National Aeronautics and
Space Administration

Washington, D.C.
20546

MAR 11 1991

Reply to Attn of: SZ

TO: Distribution

FROM: S/Associate Administrator for Space Science and Applications

SUBJECT: Gamma Ray Observatory (GRO) Prelaunch Mission Operations Report (MOR)

Enclosed for your information is the GRO Prelaunch MOR which covers the GRO deployment mission. This Observatory will be launched on the STS-37 mission in April.

The GRO is the second of four Great Observatories to be launched (the first was the Hubble Space Telescope in April 1990). Each of these complementary Observatories will view the universe in a different region of the electromagnetic spectrum. Together, the Great Observatories will enable the international science community to study astronomical objects in ways never before possible.

This Observatory is the first spacecraft with a complement of large sophisticated instruments designed to study a broad range of gamma ray energies. It will be placed in a 450 km circular orbit by the Space Shuttle Atlantis. After about 5 weeks of activation, checkout, and calibration, the spacecraft will begin a year-long all sky survey of the gamma ray universe. In later years it will view in greater detail intriguing objects identified by the survey.

This MOR (a) describes the objectives of the GRO mission; (b) provides a discussion of the mission deployment; (c) provides a brief description of the Observatory and its scientific instruments; and (d) outlines the ground operations elements required to support its launch, deployment, activation, and science operations.

L. A. Fisk

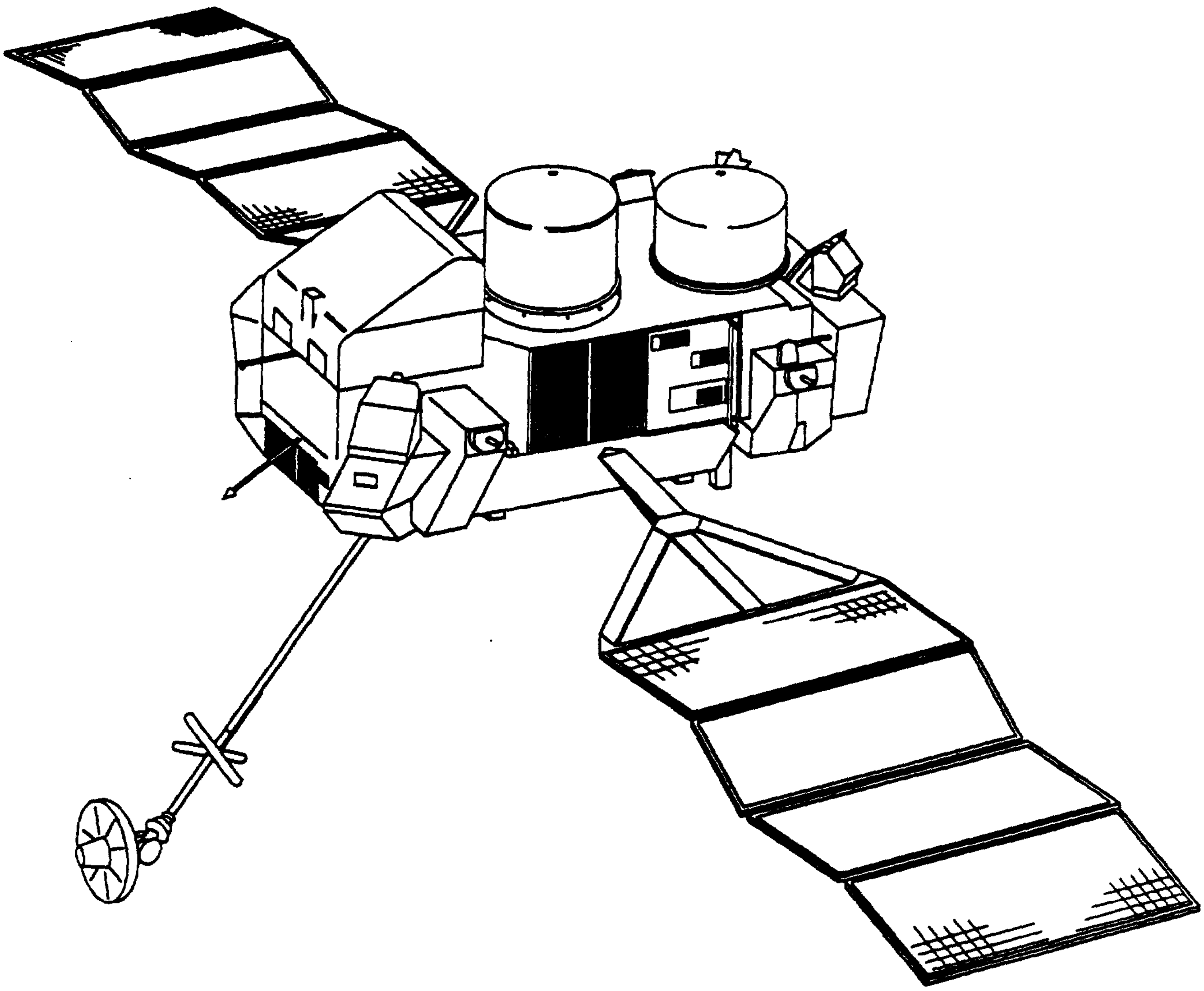
Enclosure

National Aeronautics and
Space Administration

Mission Operations Report

OFFICE OF SPACE SCIENCE AND APPLICATIONS

REPORT NO. E-S-458-31-91-01



GAMMA RAY OBSERVATORY

(GRO)

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FOREWORD

MISSION OPERATIONS REPORTS are published expressly for the use of NASA senior management, as required by the Administrator in NASA Management Instruction NMI 8610.3D, dated May 13, 1982. The purpose of these reports is to provide NASA senior management with timely, complete, and definitive information on flight mission plans, and to establish official mission objectives which provide the basis for assessment of mission accomplishment.

Reports are prepared and issued for each flight project just prior to launch. Following launch, updating reports for each mission are issued to keep management currently informed of definitive mission results as provided in NASA Management Instruction HQMI 8610.1B.

These reports are sometimes highly technical and are for personnel having program/project management responsibilities. The Public Affairs Division publishes a comprehensive series of reports on NASA flight missions which are available for dissemination to the news media.

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GAMMA RAY OBSERVATORY PROGRAM OVERVIEW

The NASA Astrophysics Program is an endeavor to understand the origin and fate of the universe, to understand the birth and evolution of the large variety of objects in the universe, from the most benign to the most violent, and to probe the fundamental laws of physics by examining their behavior under extreme physical conditions. These goals are pursued by means of observations across the entire electromagnetic spectrum, and through theoretical interpretation of radiations and fields associated with astrophysical systems.

Astrophysics orbital flight programs are structured under one of two operational objectives: (1) the establishment of long duration"Great Observatories" for viewing the universe in four major wavelength regions of the electromagnetic spectrum (radio/infrared/submillimeter, visible/ultraviolet, X-ray, and gamma ray), and (2) obtaining crucial bridging and supporting measurements via missions with directed objectives of intermediate or small scope conducted within the Explorer and Spacelab programs. Under (1) in this context, the Gamma Ray Observatory (GRO) is one of NASA's four "Great Observatories". The other three are the Hubble Space Telescope (HST) for the visible and ultraviolet portion of the spectrum, the Advanced X-ray Astrophysics Facility (AXAF) for the X-ray band, and the Space Infrared Telescope Facility (SIRTF) for infrared wavelengths.

GRO's specific mission is to study the sources and astrophysical processes that produce the highest energy electromagnetic radiation from the cosmos. The fundamental physical processes that are known to produce gamma radiation in the universe include nuclear reactions, electron bremsstrahlung, matter-antimatter annihilation, elementary particle production and decay, Compton scattering, synchrotron radiation. GRO will address a variety of questions relevant to understanding the universe, such as: the formation of the elements; the structure and dynamics of the Galaxy; the nature of pulsars; the existence of black holes; the possible existence of large amounts of antimatter; energetic and explosive phenomena occurring in galactic nuclei; the origin of the cosmic diffuse background; particle acceleration in the Sun, stars and stellar systems; processes in supernovae; and the origin and evolution of the universe itself. This is achieved through use of four independent and complementary instruments developed by different Principal Investigator Teams. These instruments cover different, but overlapping, energy bands ranging from 10 keV to 30 GeV and are much larger and much more sensitive than any gamma-ray instruments previously flown in space.

GRO is a NASA cooperative program. The Federal Republic of Germany, with co-investigator support from The Netherlands, the European Space Agency, the United Kingdom, and the United States, has principal investigator responsibility for one of the four instruments. The Federal Republic of Germany is also furnishing hardware elements and co-investigator support for a second instrument.

GRO was originally conceived, designed, and developed as a Principal Investigator class mission in recognition of the complex nature of the instruments required. A plan to extend its mission lifetime led to its inclusion in NASA's Great Observatory Program and the need for a vigorous Guest Investigator program to maximize scientific productivity. The mission is structured in four phases: Phase 1 will last 15 months, during which the GRO Instrument Teams will carry out an all-sky survey and other high priority observations; Phase 2 will last one year, with 30 percent of the observing time allocated to Guest Investigators; Phase 3 will also last one year, with 50 percent of the observing time allocated to Guest Investigators; Phase 4 allocations have not been determined at this time. The data analysis associated with each instrument requires a high degree of familiarity with the instrument, requiring the Guest Investigators, in the early phases of the program, to

work directly and closely with one or more of the GRO Instrument Team scientists or the Instrument Specialists in the GRO Science Support Center. In later phases of the mission, Guest Investigators may propose to work with less dependence on the Instrument Team.

The GRO spacecraft is a 3-axis stabilized, free-flying spacecraft with a gross weight of 15900 kg of which approximately 6000 kg is scientific payload. It is capable of pointing at any celestial target for long periods of time (days to weeks). Celestial pointing is to be maintained with an accuracy of 0.5 degrees. Attitude determinations will provide knowledge of the pointing direction to an accuracy of 2 arcminutes. Absolute timing is to be accurate to 0.1 millisecond. GRO has an onboard propulsion system with approximately 1900 kg of monopropellant hydrazine. This system is to be used routinely for attitude control and for maintaining the desired orbital altitude. Sufficient fuel is to be retained for a controlled reentry. Primary electrical power of 4000 watts is provided by two silicon solar cell arrays. Approximately 2000 watts are available for the Observatory, with nickel-cadmium (NiCd) batteries supplying power during eclipse periods.

GRO is a dedicated Space Shuttle mission and requires approximately one-half the volume of the shuttle payload bay. The shuttle is to place the Observatory directly into the desired circular orbit at an altitude of 450 km at 28.5° inclination. If orbit injection occurs at a lower altitude, GRO's onboard propulsion system will be used to achieve the initial operational orbit at 450 km. GRO will subsequently be maintained at an altitude between 450 and 440 km until the propellant is reduced to the level required for a controlled reentry into the ocean. This range of altitudes was selected because at lower altitudes the Observatory would encounter excessive drag and at higher altitudes it would be exposed to higher levels of background radiation. If radiation levels near 450 km are found to be lower than anticipated, a higher maximum altitude could be selected to extend mission life. An expected orbital lifetime of about 10 years has been calculated assuming deployment of the GRO in the 450 km circular orbit is accomplished.

Nominal GRO timelines for launch and prelaunch operations specify selected functional checkouts in the Orbiter bay, beginning 21 hours after lift-off. Removal from the bay with the Remote Manipulator System (RMS) and release from the RMS will take place on Flight Day 3. Solar arrays and the high gain antenna are deployed, and batteries are taken through one charging cycle, while GRO is attached to the RMS. The shuttle will move away from GRO following release. Completion of spacecraft activations and checkout of the attitude control system will be completed on Flight Day 5. Science instrument activation begins on Flight Day 5, and the science mission is expected to begin begin, on Day 19.

NASA's Tracking and Data Relay Satellite System (TDRSS) and Communications Network (NASCOM) will link GRO to the GRO Payload Operations Control Center (POCC) in the Multisatellite Operations Control Center (MSOCC) at the Goddard Space Flight Center (GSFC). Real time data are to be transmitted at 32 kbps and the onboard tape recorder dumps the data at 512 kbps every other orbit. GRO's onboard Communications and Data Handling System (C&DH) is based on a standard NASA module that has been modified to provide a packetized telemetry data system, which will permit rapid data capture and delivery, via NASCOM, to geographically distributed users. Science data and the required auxiliary data (e.g., attitude, orbit parameters, mode ID's, etc.) are merged and put into telemetry packets onboard the spacecraft. This eliminates the need for merging science data and auxiliary data on the ground prior to delivery to the science investigators. Each of the GRO Principal Investigator Instrument Teams has established data processing facilities with associated software for analyzing data from its instrument. The GRO Science Support Center at GSFC will coordinate data access, distribution, and archiving activities.

MISSION OBJECTIVES

Primary Objective:

- The ultimate success of the Gamma Ray Observatory Mission will be judged on the basis of obtaining two years of gamma-ray measurements (10 KeV to 30 GeV) covering close to the entire celestial sphere, with instruments that provide an order of magnitude greater sensitivity and accuracy than previously-flown gamma-ray missions.

Secondary Objectives:

- Provide a uniform full-sky gamma-ray survey using the wide-field imaging instruments, and make selected high-priority observations using the narrow aperture and independently-oriented instruments.

- Provide Guest Investigators 30 percent of the observation time at the completion of phase I (first 15 months) and 50 percent of the observation time at the completion of phase II (an additional 12 months).

Douglas R. Broome Jr.
GRO Program Manager

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SCIENTIFIC OBJECTIVES

Introduction

Gamma-ray astronomy, the study of the highest energy electromagnetic radiation from the cosmos, provides the most direct measurements of the presence and dynamic effects of energetic charged particles, element synthesis, and particle acceleration both within and outside the Galaxy. The scientific questions that GRO is uniquely designed to address include: In what settings and by what processes are charged particles accelerated to relativistic speeds? Is the universe made up of entirely of *matter*, or could there be balancing regions of *antimatter*? How were the elements created that make up today's universe? What is the nature of quasars and what is the source of their incredible power? What happens in a supernova explosion? What causes the sporadic intense bursts of radiation called "gamma ray bursts"? What is the origin of the cosmic gamma-ray background radiation? Because gamma rays have a very low interaction cross-section and no electrical charge, they have a very high penetrating power and can reach the solar system, and the top of the Earth's atmosphere, from essentially any part of the Galaxy or Universe with their paths unaffected by magnetic fields. On the other hand, the atmosphere is opaque to gamma rays; hence, the observations must be made from space. The gamma-ray photons observed in space have retained the detailed imprint of spectral, directional, and temporal features imposed at their birth, even if they were born deep in regions opaque to visible light and X rays, or at times far back in the evolutionary history of the Universe.

The full range of gamma rays covers many decades of energy, from the merger with X rays near 20 keV to energies in excess of 100 Gev. A variety of physical processes are involved in the production of gamma rays and many of these processes are not detectable in any other part of the electromagnetic spectrum. Thus, the study of gamma rays opens a new window, not only to the Universe, but to a whole new realm of astrophysical processes. Some of the physical processes which can be uniquely examined using gamma rays are: (a) nuclear interactions of energetic nuclei observable through their gamma-ray products, (b) electromagnetic processes characteristic of energetic electrons as observed through their synchrotron, bremsstrahlung, and Compton emissions, (c) gamma-ray line-producing processes such as radioactive decay, cyclotron processes, cosmic-ray interactions, etc., (d) matter-antimatter annihilations such as baryons-antibaryons and electron-positron, and (e) poorly understood relativistic processes in supergravity (e.g., quasar, black hole, galactic nuclei) systems.

GRO will be the world's first satellite to provide an all-sky mapping of the cosmos at gamma-ray energies. Of the 30 or so discrete gamma-ray sources observed to date, only a fraction have been iidentified with objects observed at other wavelengths. This is a result of limited sensitivity and angular resolution in previous gamma-ray instruments. GRO, with its unprecedented advance in sensitivity (over a factor of 10 beyond previous instruments), will allow detailed localization and study of these sources and will increase the number of known sources to several hundred. The most energetic objects in the universe, including supernovae, neutron stars, black holes, cores of galaxies, and quasars, are known, or predicted to be intense sources of gamma ray emissions. Locations and optical identifications, based on gamma ray observations, are needed for a thorough understanding of these objects. In addition, spectral measurements will address the formation of elements by nucleosynthesis in supernovae and novae. Time variability studies will address the nature of neutron stars, pulsars and the energy production processes in the active galaxies.

Gamma-ray emissions are also observed in the form of diffuse glows in the plane of the Galaxy, extended sources in the Galaxy, and relatively uniform diffuse extragalactic background radiations. Some unknown fraction of the galactic diffuse glows comes from

emissions from unresolved discrete sources; the remainder may be attributed to cosmic-ray interactions with other matter in the interstellar medium. Extended galactic sources are, in particular, believed to be principally caused by cosmic-ray interactions with various distributions of gas and dust in interstellar space, which means that gamma rays can be a useful tool for exploring the structure and dynamics of the Milky Way.

Celestial gamma rays have also been observed in the form of intense bursts, implying transient sources, lasting only a fraction of a second to about 100 seconds. They were first observed by Vela spacecraft in 1967 and roughly 100 bursts per year have since been recorded. Although intensely studied, subject to the unpredictability of their occurrence and difficulties imposed by their short duration, they are still not well understood. A galactic origin related to neutron stars is favored by the most recent theories. Transient gamma-ray emissions of a different nature are also produced during solar flares. GRO is particularly well instrumented for burst studies and includes modes that will provide unique information for studying flare acceleration mechanisms.

Objective Outline

Based on the scientific rationale for the GRO program and the recommendations of the Committee on Space Astronomy and Astrophysics of the National Academy of Science's Space Science Board, the GRO Science Working Team adopted the following set of scientific objectives:

- A study of discrete objects such as black holes, neutron stars, and objects emitting only at gamma-ray energies.
- A search for gamma-ray line emissions indicative of sites of nucleosynthesis (the fundamental process in nature for building up the heavy elements) and other gamma-ray lines emitted in astrophysical processes.
- The exploration of the Galaxy in gamma rays in order to study the origin and dynamic pressure effects of the cosmic-ray gas and the structural features revealed through the interaction of the cosmic rays with the interstellar medium.
- A study of the nature of other galaxies as seen at gamma-ray wavelengths, with special emphasis on radio galaxies, Seyfert galaxies and Quasi Stellar Objects.
- A search for cosmological effects, through observations of the diffuse gamma radiation, and for possible primordial black hole emission.
- Observations of gamma-ray bursts, their luminosity distribution, their spectral and temporal characteristics and their spatial distribution.
- Map the distribution of diffuse gamma-ray line emission (positron annihilation at 0.511 MeV and ^{26}Al decay at 1.809 MeV) to determine its origin.

Observing Plan

Four complementary instruments, described in a following section, are required to fulfill the program objectives. Their optimum energy ranges and prime functions are noted below:

BATSE: The Burst and Transient Source Experiment will monitor the entire unocculted sky for transient events and bursts and it will provide burst trigger signals to other instruments. BATSE is optimized for the 60 keV to 600 keV

range with secondary, lower sensitivity, spectroscopic detectors covering the range from 10 keV to 100 MeV.

OSSE: The Oriented Scintillation Spectrometer Experiment will observe line and continuous gamma-ray sources in the 0.1 to 10 MeV range and solar gamma rays and neutrons above 10 MeV.

COMPTEL: The Imaging Compton Telescope will perform a very sensitive celestial survey in the 1 to 30 MeV range with a wide field of view, good angular resolution, and low background.

EGRET: The Energetic Gamma-Ray Experiment Telescope will search for diffuse and discrete gamma-ray sources from 30 MeV to 30 GeV and it will measure their intensity, energy spectrum, position, and time variations.

The objective of the first phase (15 months) of the mission is to provide a nearly uniform full-sky survey for the two wide-field imaging instruments, COMPTEL and EGRET, while at the same time providing for high priority observations by the narrow aperture and independently-oriented OSSE experiment. The BATSE instrument has continuous sensitivity to the entire unocculted sky and will observe bursts, solar flares, and other transients.

The all-sky survey is to be achieved with a series of thirty-three two-week (nominal) exposures by the COMPTEL and EGRET instruments which are co-aligned with the Z-axis viewing direction (see Figures 1 and 2). The sky-survey viewing plan is constrained by spacecraft thermal and electrical considerations, based on the Sun's location, and by the requirement that likely discrete sources of gamma radiation be observable by the OSSE experiment. The OSSE detectors can point over a range of 180° about the Y-axis; this permits OSSE to observe sources in the X-Z plane. Hence, for each Z-axis pointing of the spacecraft, an X-axis orientation is chosen to provide secondary targets for OSSE. Figure 3 is a Galactic map of the different Z-axis pointing directions to illustrate the degree of uniformity provided by a preliminary plan for a June 4, 1990 launch. The ellipses represent an approximation to the field of view of one of the wide-field instruments at the one-half sensitivity level and the numbers indicate the sequence of different Z-axis pointing directions. The actual pointing directions and the sequence will depend on the actual launch date.

Deviations from the all-sky survey plan are to be considered if an unusual astrophysical event happens to occur during the survey phase. This could extend the 15 months required to complete the survey.

Observing plans for subsequent phases will be based on priority observations selected by the Principal Investigator Teams, the findings from Phase 1, and the priorities assigned to Guest Investigator proposals requesting observing time. During Phase 2, lasting one year, 30 percent of the total observing time is to be allocated to Guest Investigators proposing OSSE, COMPTEL, and EGRET investigations. During Phase 3, also lasting one year, 50 percent of the total observing time on OSSE, COMPTEL, and EGRET will be allocated to Guest Investigators. Observing allocations for Phase 4, the remainder of the mission, are to be determined at a later date. BATSE will continue to monitor for gamma ray bursts and other transient sources.

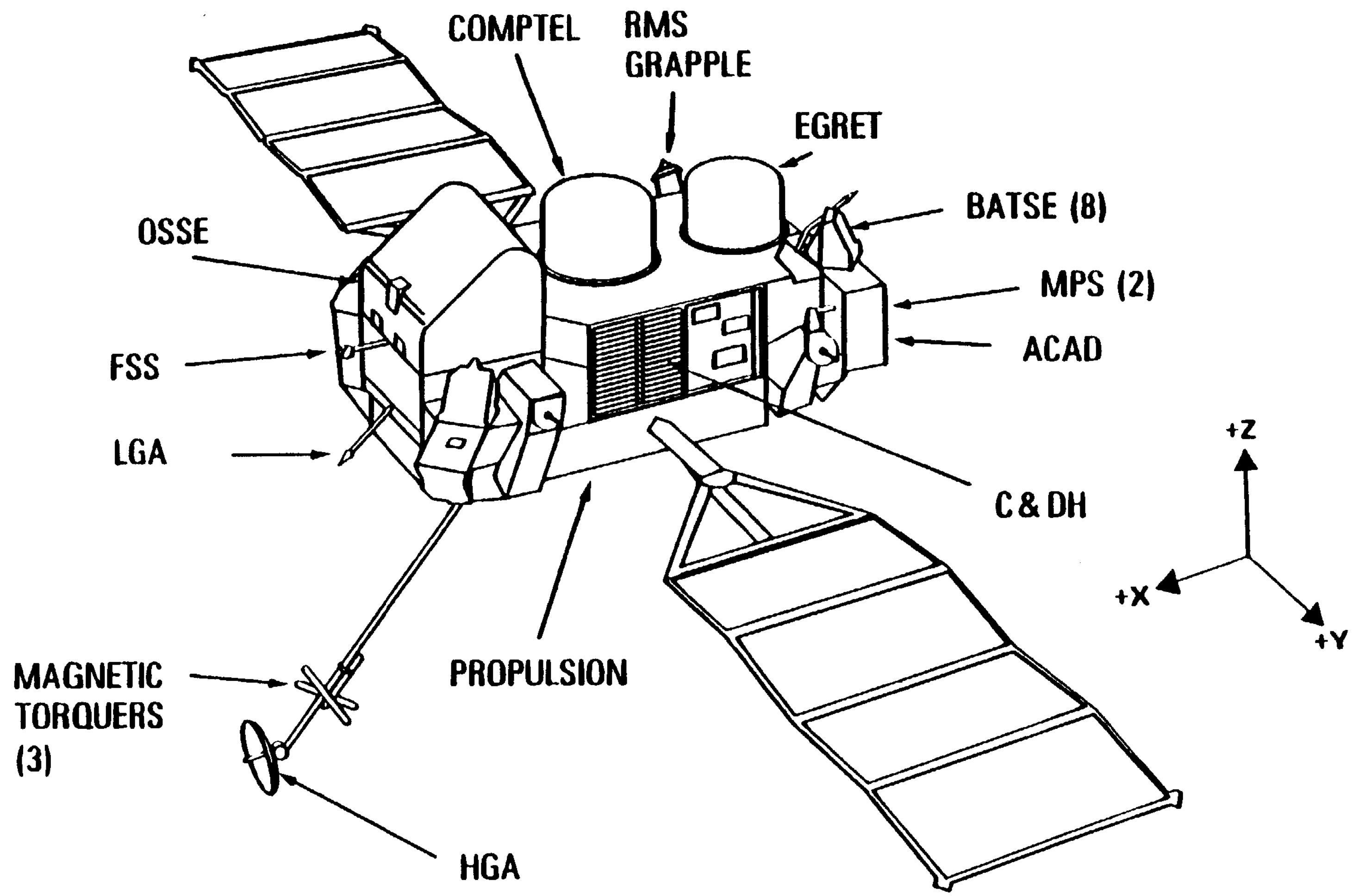


Figure 1. GRO Configuration (Top View)

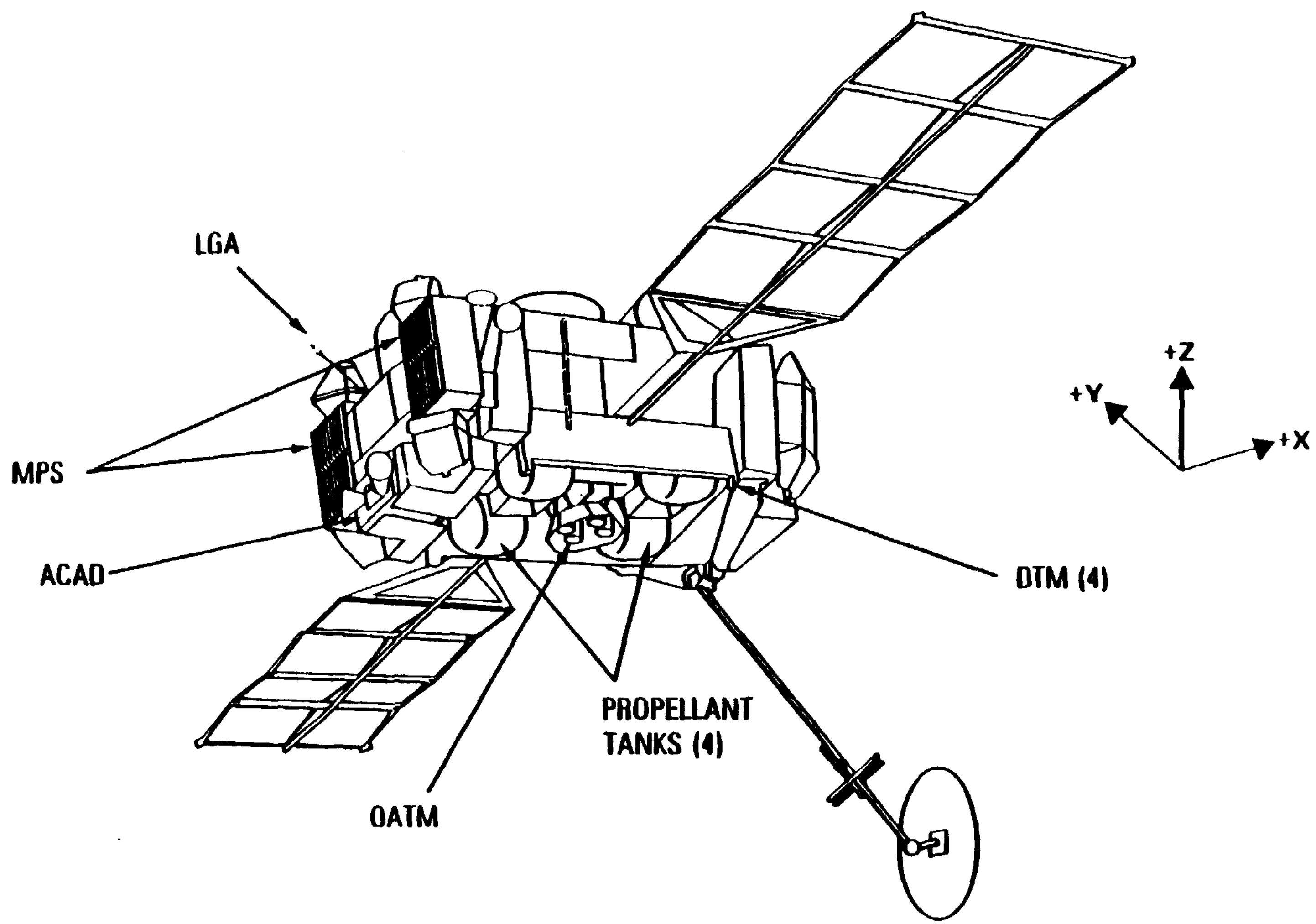


Figure 2. GRO Configuration (Bottom View)

Galactic Coordinates

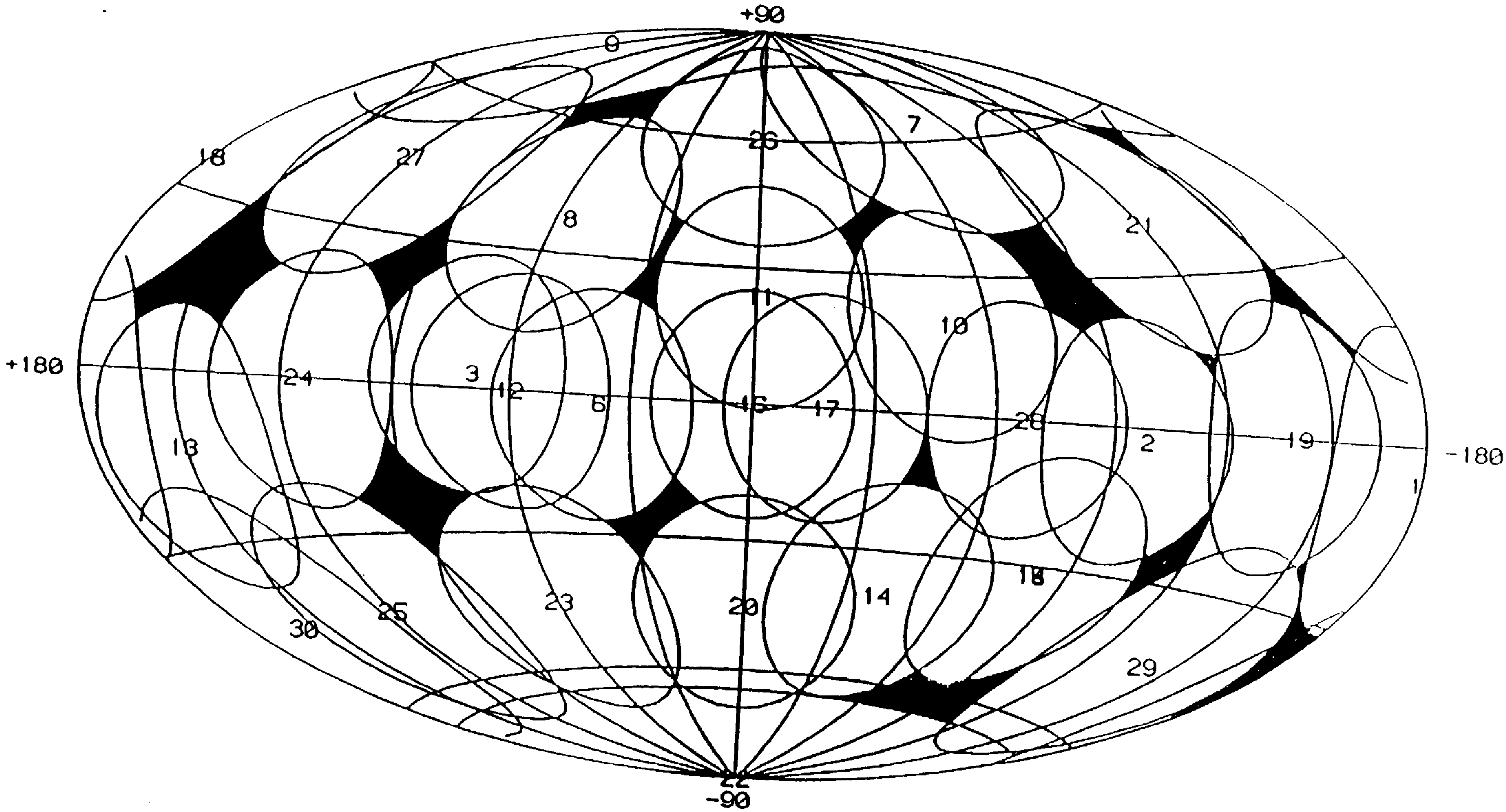


Figure 3. Illustrative Full Sky Observing Plan

SCIENCE INSTRUMENTS

General

The four GRO instruments represent an integrated complement whose common goal is the detailed study of the celestial gamma-ray spectrum. Collectively, the selected instruments span the photon spectrum from 10 keV to 30 GeV, almost 6 decades in energy. Each instrument has been chosen such that its sensitivity regions overlap those of its nearest neighbors, thus allowing for complete continuity of spectral measurements and cross-calibration of each of the instruments (see Figure 4). Without exception, each instrument represents a major step forward in experimental capability. The photon sensitivity over the entire 6-decade range has been improved by more than an order of magnitude over the best previously flown instruments. Significant improvements in angular resolution have also been made. Salient instrument characteristics are summarized in Table 1.

The Principal Investigator(s) and Co-Investigators that constitute each Instrument Team are listed in Table 2, together with their respective institutions and major responsibilities.

The Burst and Transient Source Experiment (BATSE)

(a) BATSE Instrument Objectives

The BATSE is designed for continuous monitoring of a large fraction of the sky so that gamma-ray bursts and other transient sources can be detected, located and studied. There are at least three different classes of gamma-ray bursts which have distinct spectral and temporal characteristics. These three classes may indicate vastly different energy production mechanisms for gamma-ray bursts or even different types of emitting objects. Many models of gamma-ray bursters have been developed by theorists. In recent years, most models contain a neutron star as the central object. Among the events which are speculated to trigger a gamma-ray burst are: a starquake in the neutron star, a compact object impacting the surface of a neutron star, or a thermonuclear explosion of material accumulated on the neutron star surface.

One of the unique features of gamma-ray bursts is their extreme variability on short timescales. The BATSE detector array will be able to observe variations on timescales as short as several microseconds. Observations of fast time variations will allow models of emission mechanisms and source geometry to be studied in detail. Spectral variations on timescales as short as 0.1 millisecond will also be observed. Such measurements will allow the testing of candidate emission mechanisms. For example, models based on radioactive decay, inverse Compton emission, and synchrotron emission, following sudden injection of relativistic electrons into a strong magnetic field, would each predict different spectral variations during a burst.

Of prime importance in the study of gamma-ray bursts is the location of the burst with high accuracy so that optical and/or radio counterparts may be found and studied. The best method to obtain arcminute class locations is through an interplanetary network of burst detectors. By recording the time of arrival of a burst at widely separated locations, the burst location is accurately determined by triangulation methods. The GRO burst detectors are expected to be a key element of this network due to their high sensitivity and accurate timing capabilities. The detectors on interplanetary spacecraft are, of necessity, small and relatively insensitive. As a result, only the strongest bursts can be located by the existing network. Numerous additional bursts, too weak to be detectable by the interplanetary network, will be detectable with the large-area detectors aboard GRO. Their positions may

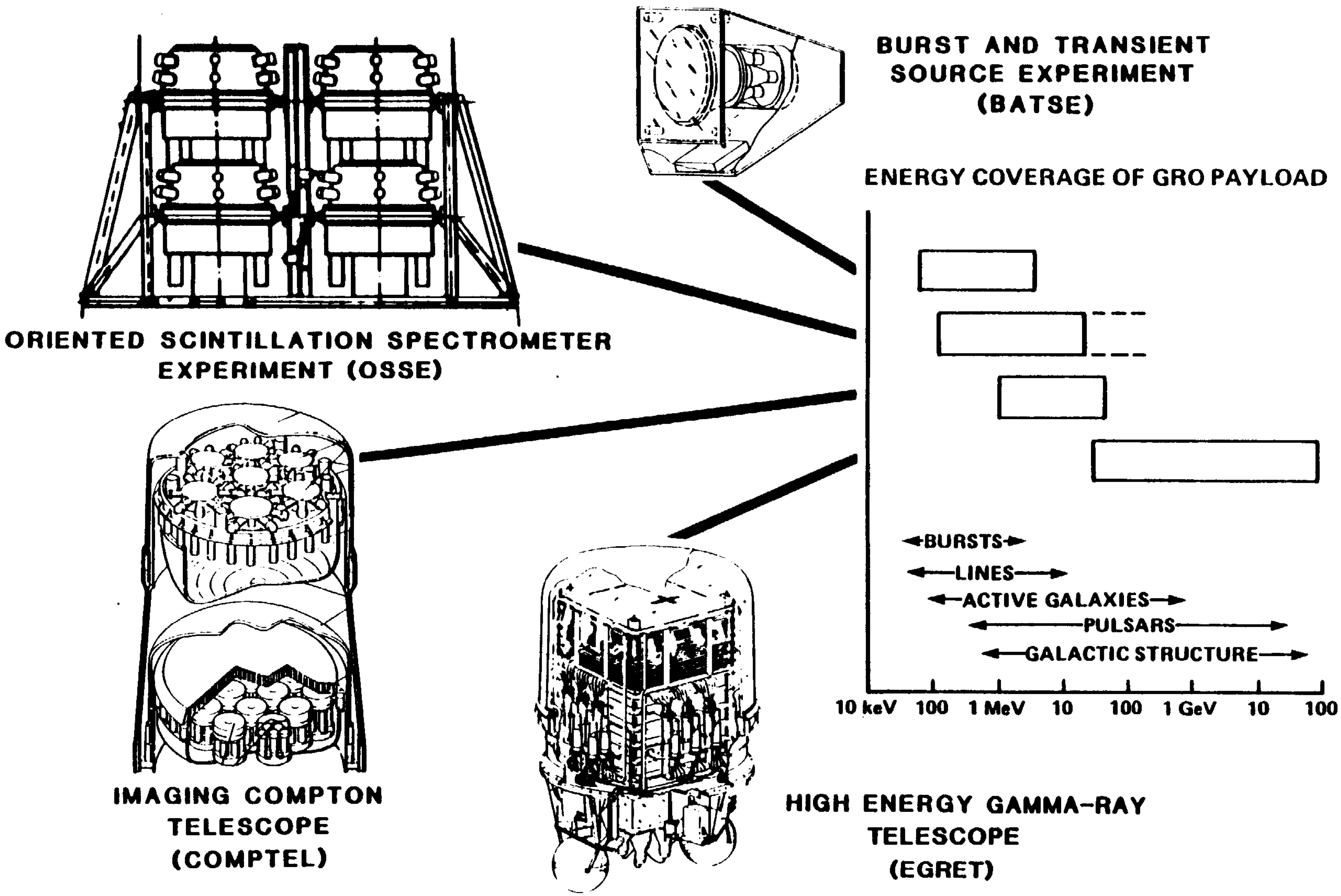


Figure 4. GRO Science Instruments

Table 1. Summary of GRO Instrument Characteristics

	BATSE		OSSE	COMPTEL	EGRET
	LARGE AREA	SPECTROSCOPY			
ENERGY RANGE (MeV)	0.03 to 1.9	0.015 - 110	0.10 to 10.0	1.0 to 30.0	20 to 3×10^4
ENERGY RESOLUTION (FWHM)	32% at 0.06 MeV 27% at 0.09 MeV 20% at 0.66 MeV	8.2% at 0.09 MeV 7.2% at 0.66 MeV 5.8% at 1.17 MeV	12.5% at 0.2 MeV 6.8% at 1.0 MeV 4.0% at 5.0 MeV	8.8% at 1.27 MeV 6.5% at 2.75 MeV 6.3% at 4.43 MeV	~20% 100 to 2000 MeV
EFFECTIVE AREA (cm^2)	1000 ea. at 0.03 MeV 1800 ea. at 0.1 MeV 550 ea. at 0.66 MeV	100 ea. at 0.3 MeV 127 ea. at 0.2 MeV 52 ea. at 3 MeV	2013 at 0.2 MeV 1480 at 1.0 MeV 569 at 5.0 MeV	25.8 at 1.27 MeV 29.3 at 2.75 MeV 29.4 at 4.43 MeV	1200 at 100 MeV 1600 at 500 MeV 1400 at 3000 MeV
POSITION LOCALIZATION (STRONG SOURCE)	1° (strong burst)	—	10 arc min square error box (special mode; 0.1 x Crab spectrum)	8.5 arc min (90% confidence at 2.75 MeV - 20σ source)	5 to 10 arc min (1σ radius; 0.2 x Crab spectrum)
FIELD OF VIEW	4 π sr	4 π sr	3.8° x 11.4°	~64°	~0.6 sr
MAXIMUM EFFECTIVE GEOMETRIC FACTOR (cm^2 sr)	15000	5000	13	30	1050 (~500 MeV)
ESTIMATED SOURCE SENSITIVITY (106 sec; off Galactic plane) LINE		0.4% equivalent width (5 sec integration)	$(2\text{-}5) \times 10^{-5}$ $cm^{-2}s^{-1}$	3×10^{C} to 3×10^{-6} $cm^{-2}s^{-1}$	
CONTINUUM	6×10^{-8} erg cm^{-2} (10 sec - burst)		2×10^{-7} $cm^{-2}s^{-1}$ keV^{-1} (@ 1 MeV)	5×10^{-5} $cm^{-2}s^{-1}$	5×10^{-8} $cm^{-2}s^{-1}$ (>100 MeV) 1.5×10^{-8} $cm^{-2}s^{-1}$ (>1000 MeV)
MASS (kg)	976		1805	1460	1813
DIMENSIONS (m)	0.76 x 0.66 x 0.78 each		1.57 x 1.78 x 2.11	1.70 diam. x 2.63	1.65 diam. x 2.25
POWER (W)	117		192	206	190
DATA RATE (bps)	3555		6492	6125	6859

Table 2. GRO Instrument Teams

BATSE

Institution	*Personnel*	*Responsibilities*
Marshall Space Flight Center	G. J. Fishman, PI C. A. Meegan, Co-I T. A. Parnell, Co-I R. B. Wilson, Co-I	Experiment management, hardware, software, and data analysis
University of California, San Diego (UCSD)	J. L. Matteson, Co-I	Flight hardware components, and data analysis
Goddard Space Flight Center	B. J. Teegarden, Co-I T. L. Cline, Co-I	Data analysis
University of Alabama, Huntsville (UAH)	W. S. Paciesos, Co-I	Test and calibration, data analysis, and mission operations

OSSE

Institution	*Personnel*	*Responsibilities*
Naval Research Laboratory (NRL)	J. D. Kurfess, PI W. N. Johnson, Co-I G. H. Share, Co-I R. L. Kinzer, Co-I M. S. Strickman, Co-I	Program management, ground support equipment, flight software, instrument, scintillator, and phototube subcontracts; calibration, integration, mission operations, and data analysis
Northwestern University (NU)	M. Ulmer, Co-I	Science data processing and data analysis
Royal Aerospace Establishment, Farnborough, England	C. Dyer, Co-I	Detector background model and data analysis
Clemson University (CU)	D. D. Clayton, Co-I	Data analysis and theoretical interpretations

Table 2. GRO Instrument Teams (continued)

COMPTEL

Institution	*Personnel*	*Responsibilities*
Max-Planck-Institute for Extraterrestrial Physics, Garching, West Germany	V. Schönfelder, PI G. Lichti, Co-I R. Diehl, Co-I	Program management, lower detector, veto domes, instrument integration and calibration, and data analysis
Laboratory for Space Research, Leiden, Netherlands	B. N. Swanenburg, Co-I W. Hermsen, Co-I H. Aarts, Co-I	Analog electronics, low voltage power supply, and data analysis
University of New Hampshire	J. A. Lockwood, Co-I W. R. Webber, Co-I J. Ryan, Co-I	Upper detector assembly, front-end-electronics, and data analysis
European Space Agency (ESA) ESTEC, Noordwijk, Netherlands	K. Bennett, Co-I B. G. Taylor, Co-I	Digital electronics, inflight calibration sources, ground support equipment, and data analysis

EGRET

Institution	*Personnel*	*Responsibilities*
Goddard Space Flight Center	C. E. Fichtel, Co-PI R. C. Hartman, Co-I D. A. Kniffen, Co-I D. J. Thompson, Co-I D. L. Bertsch, Co-I	Program management, spacecraft interface, spark chambers, thermal analysis, data analysis, mechanical structure, time-of-flight electronics, digital data handling electronics instrument integration software, and software system
Stanford University	R. Hofstadter, Co-PI* E. B. Hughes, Co-I* P. Nolan, Co-I	Lower crystal, packaging, and electronics; data analysis; energy calibration and calibration facility
Max-Planck-Institute for Extraterrestrial Physics, Garching, West Germany	K. Pinkau, Co-PI H. A. Mayer-Hasselwander, Co-I H. Rothermel, Co-I M. Sommer, Co-I G. Kanbach, Co-I	Anticoincidence dome and electronics, data analysis, pressure vessel, and calibration fixture
Grumman Aerospace Corp.	A. Favale, Co-I E. Schneid, Co-I	Calibration, instrument integration, and data analysis

* Deceased

be determined to within a few degrees by GRO alone, depending on their intensity, by comparing the responses of individual BATSE detectors pointed in different directions. The detection by GRO of hundreds of gamma-ray bursts (anticipated within a two year period) will allow relatively accurate determination of the distribution of these sources in the Galaxy, and possibly the identification of some bursts with extragalactic objects. For the first time, these burst locations will become available within days of their occurrence. The coarse location of bursts will also enable deep, wide-field, optical photographs to be taken of those regions.

Another objective of the BATSE is to provide the GRO with a full-sky monitor of long-lived strong sources. The other experiments on the GRO have limited fields of view and are constrained in their pointing capability. The BATSE will be able to detect and locate strong transient sources and outbursts of known sources from all regions of the sky. The BATSE instrument can also study the stronger pulsing hard x-ray and gamma-ray sources from all parts of the sky anytime during the mission.

(b) BATSE Instrumentation

The instrument consists of eight wide-field detector modules, with one module at each of the eight corners of the GRO spacecraft to permit maximum unobstructed, continuous viewing of the sky. All modules have identical configurations as shown in Figure 5. Each module contains two detectors: a large-area detector, optimized for broad energy coverage and directional response, and a spectroscopy detector, optimized for broad energy coverage and good energy resolution.

The main detector is a disk of sodium iodide (NaI) scintillation crystal, 20 inches in diameter and 1/2-inch thick. A light collector housing on each detector couples the scintillation light into three, 5-inch diameter photomultiplier tubes. An anticoincidence shield on the front side is used to reduce the background due to charged particles, and a thin lead and tin shield inside the light housing reduces the amount of background and scattered radiation entering the backside. The spectroscopy detector is a 5-inch diameter, 3-inch thick, NaI scintillation crystal. Signals from the detectors are processed in the detector electronics unit and routed to the central electronics unit for digital processing. The central electronics unit is a microprocessor-based data system that processes and stores large amounts of data from all 16 detectors in various formats. It takes one orbit to read out the data from a burst. At other times, background and calibration data are recorded along with data used to study long-lived transients and pulsing sources. Of particular importance for obtaining calibration data are the observations of solar flares and the emission from hard x-ray sources such as that in the Crab nebula. Other long-lived hard x-ray and gamma-ray sources can be observed as they are occulted by the earth each orbit.

It is expected that the BATSE will discover from 100 to 400 bursts per year. Some of these bursts will be in the field of view of other experiments, in which case time profiles, spectra, and locations can be compared. An onboard burst trigger signal from BATSE will be sent to the other GRO instruments to allow other GRO detectors to gather data on the burst. A solar flare trigger signal is provided to the OSSE and COMPTEL instruments.

The Oriented Scintillation Spectrometer Experiment (OSSE)

(a) OSSE Instrument Objectives

The OSSE has been designed to undertake comprehensive observations of astrophysical sources in the 100 KeV to 10 MeV range. Secondary capabilities for gamma-ray and

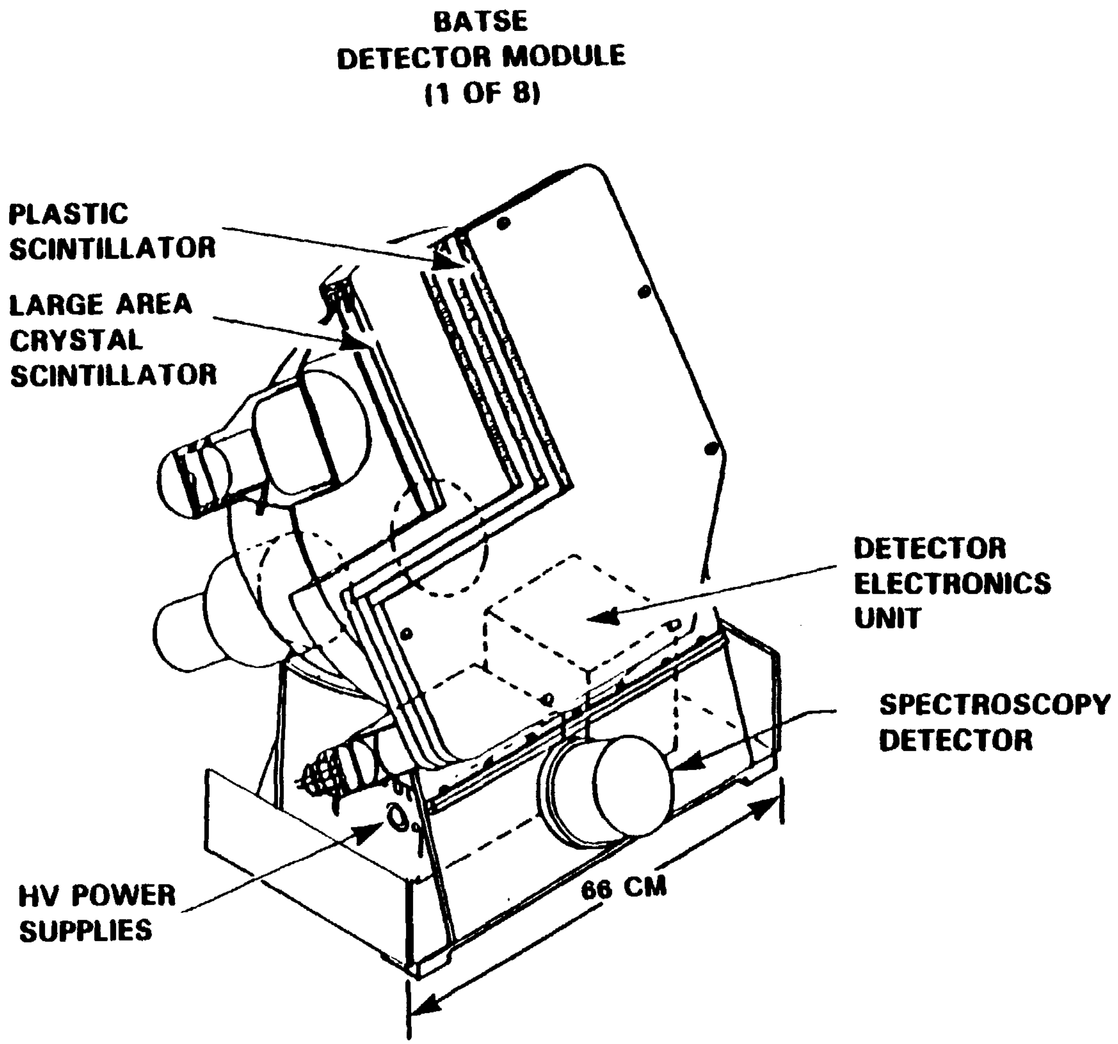


Figure 5. BATSE Detector Module

neutron observations above 10 MeV have also been included, principally for solar flare studies. The use of NaI(Tl) scintillation detectors provides a large area and high sensitivity, optimized for line and continuum measurements in the 0.1 to 10 MeV region. The highest sensitivity is maintained by implementation of an observational technique that minimizes susceptibility to background variations due to orbital geomagnetic latitude effects and spallation-produced radioactivity. This technique uses a single axis offset pointing capability to modulate a celestial source's contribution to the observed gamma-ray flux on a time scale (typically 2 minutes) that is short compared to the background variations so that it can be extracted from the background. The offset pointing capability also enables the experiment to undertake observations of selected sources, such as transient objects, at locations on the sky other than in the direction of the spacecraft Z-axis. The single axis nature of the offset pointing capability means that only a limited portion of the sky is available for any given spacecraft orientation. For example, this capability will be used to monitor solar flare activity without impacting the planned observational program of the other GRO experiments. It can also be used to observe secondary sources during orbital periods of earth occultation of the primary source.

(b) OSSE Instrumentation

Four identical detector systems are used to obtain the operational flexibility to meet the variety of objectives previously outlined. As shown in Figure 6, each of the detectors is mounted in a single axis orientation control system which provides offset pointing over a range of 192 degrees. The detectors are generally operated in co-axial pairs. While one detector of a pair is observing the source, the other detector can be offset to monitor the background. After a programmable time interval, the detectors will interchange observation directions by opposite rotations.

The primary element of each detector system is the NaI portion of a 33 cm diameter NaI(Tl)-CsI(Na) phoswich. Pulse-shape discrimination is used to distinguish energy dispositions in the NaI primary element from those in the CsI portion of the phoswich. A NaI annular shield assembly, together with the CsI portion of the phoswich, forms the active anticoincidence shield for background rejection. The angular response of a detector is defined by a tungsten alloy passive collimator also located within the NaI annular shield. The passive collimator provides the 3.8° x 11.4° rectangular field of view throughout the 0.1 - 10 MeV energy range. Each phoswich is viewed by seven photomultiplier tubes (PMT's), providing an energy resolution of 8% at 0.661 MeV. Active gain stabilization is used to maintain this energy resolution (Delta E/E of 20% in the central part of the energy range) by individually adjusting the gain of each of the seven PMT's.

The experiment's data acquisition and control system incorporates varied modes of operation depending on the type of information desired during a particular observation. Diagnostic capabilities and redundancy are important features of the system; the ability to reconfigure the experiment in the event of a failure has also been included. This versatility is achieved through use of redundant programmable microprocessors.

Energy spectra in the 100KeV - 10 MeV energy range are processed by two pulse-height analyzers for each detector. Individual spectra are accumulated and transmitted over an interval between 2 and 32 seconds depending on the instrument operating mode. Typical operating modes will use intervals of 4 or 8 seconds. Energy losses >10 MeV are processed by a third pulse-height analyzer for each detector and also read out on a 4-second time scale.

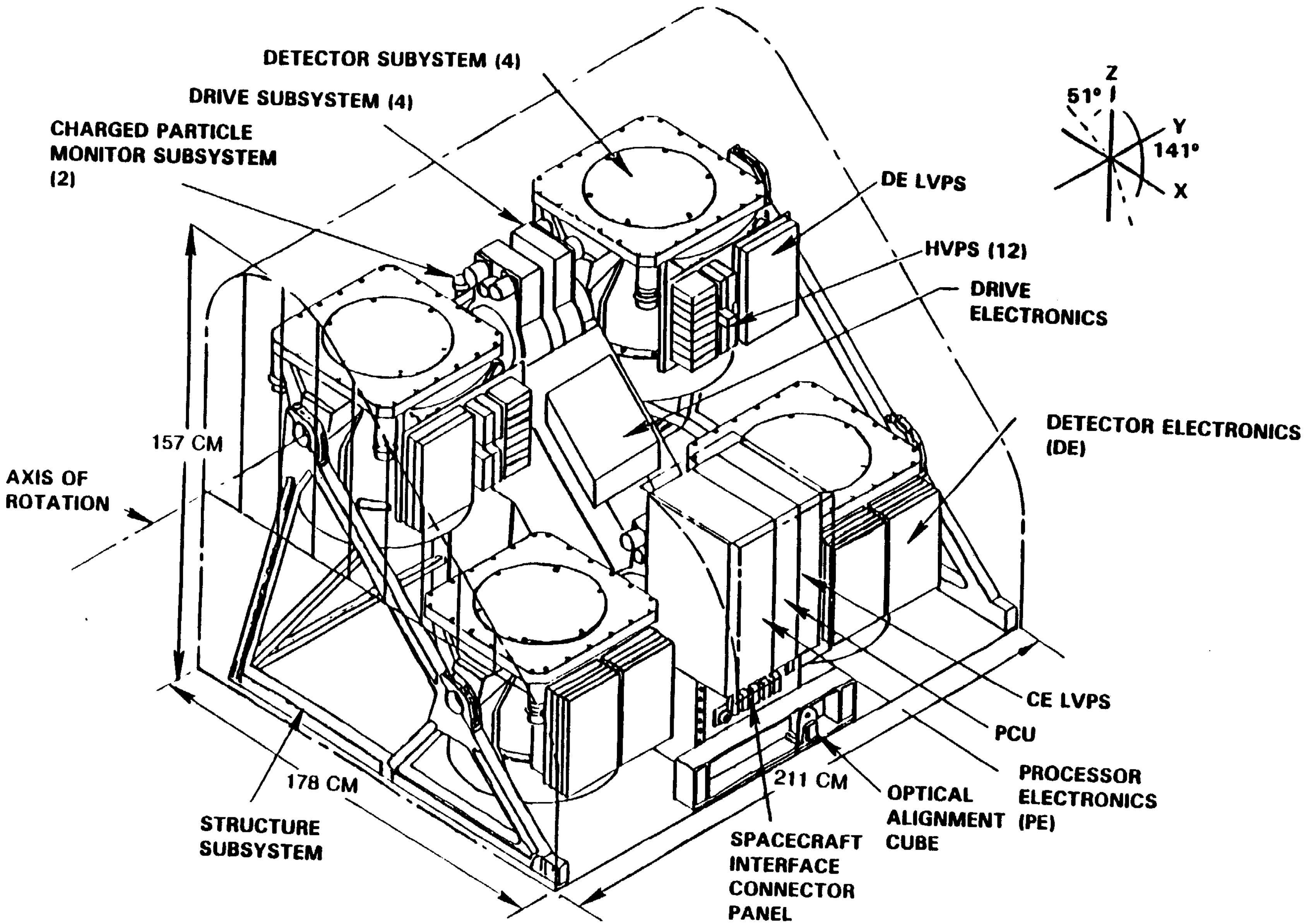


Figure 6. OSSE Assembly

An alternate data mode provides the time resolution necessary for the analysis of fast pulsars. In this mode, spectral resolution is sacrificed to obtain time resolutions of up to 0.125 msec. High time resolution studies of gamma-ray bursts are made using the active shield elements of each of the detectors. The rates from all of the elements are summed and sampled by a burst detection circuit which will store 4096 samples of the summed shield rates at up to 4 msec time resolution. Crude directionality of the burst can be obtained by comparison of the relative responses of the individual shield elements.

The Imaging Compton Telescope (COMPTEL)

(a) COMPTEL Instrument Objectives

COMPTEL has been designed to perform a very sensitive survey in the energy range from 1 to 30 MeV. It combines a wide field of view (about 1 steradian) with good angular resolution. The lack of reliable results from previous investigations in this energy range reflects the extreme observational difficulties involved. A basic problem with these measurements has been the background generated in the instruments. Therefore, a great effort has been made to minimize the background in COMPTEL so that the detection limits shall be determined only by counting statistics.

The three essential properties of the instrument: (1) imaging capability, (2) broad aperture, and (3) low background characteristics, reflect the best available techniques to achieve the principal scientific objectives. These are the study of:

- galactic and extragalactic point sources
- diffuse emission from the Galaxy
- cosmic diffuse flux
- broadened line emission

COMPTEL also provides the possibility of detecting linear polarization from strong gamma-ray sources and, like the other GRO instruments, will provide gamma-ray burst capabilities. Energy spectra of solar and cosmic gamma-ray bursts can be measured with good resolution between 0.1 and 10 MeV. Bursts that are within the field-of-view of the telescope can be located to better than 1 degree accuracy. In addition, COMPTEL has the capability to measure neutrons from solar flares, if the sun is in the field-of-view.

(b) COMPTEL Instrumentation

COMPTEL (see Figure 7) uses two detector arrays in series for detection by a two step process. In the upper one (D1) a liquid scintillator, NE 213 A, is used. In the lower one (D2) NaI(Tl) crystals are used. A gamma-ray is first Compton-scattered by interacting with an electron in D1 and the location of the interaction and the energy lost to the recoiling electron are measured. The scattered gamma-ray is then absorbed in D2 and the location and energy of the absorbed photon is measured. The energy of the incident gamma-ray is the sum of the two measured energies. The locations of the interactions in D1 and D2 define a circle in the sky where the gamma ray originated. After numerous photons have been recorded and sorted, the direction of the source can be determined by comparing where the paths of the circles intersect. The 1-sigma angular resolution is 1.3° at 2.75 MeV, slightly greater below, and less above, this energy. The energy resolution is about 8% at 1 MeV and less than 6.5% above 4 MeV.

As shown in Figure 7, the two detectors are separated by a distance of 1.5 m. Each detector is entirely surrounded by a thin anticoincidence shield (consisting of two plastic

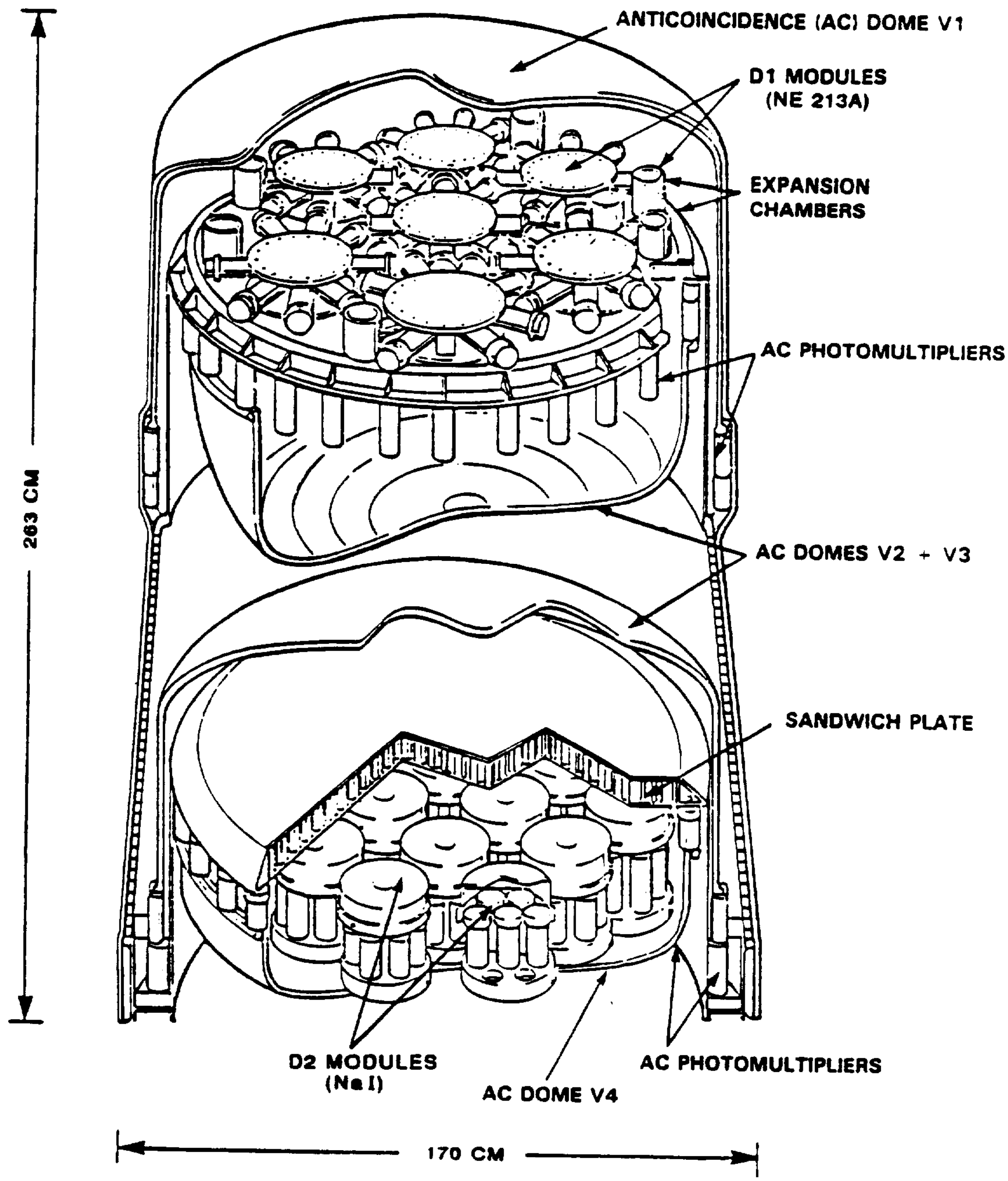


Figure 7. COMPTEL Detector Assembly

scintillator domes) which provide the basic information necessary to recognize (and thereby disregard the effects of) charged particles. Between both detectors there are two small plastic scintillation detectors containing weak Cobalt 60 sources; these are used as gamma-ray calibration sources.

The upper detector (D1) consists of 7 cylindrical modules of liquid scintillator NE 213 A. Each module is approximately 28 cm in diameter and 8.5 cm thick and is viewed radially by 8 photomultiplier tubes. The total area of D1 is 4310 sq cm. The lower detector (D2) consists of 14 cylindrical NaI(Tl) blocks, 28 cm in diameter and 7.5 cm thick, which are mounted on a baseplate with a diameter of about 1.5 m. Each NaI block is seen from below by seven, 7.5 cm photomultipliers. The total geometrical area of D2 is 8620 sq cm. Each anticoincidence shield consists of two 1.5 cm thick domes of plastic scintillator NE 110. A dome is viewed by 24 photomultipliers. Except for the front-end electronics of the photomultipliers, all main electronics are mounted on a platform outside the detector assembly.

Each calibration source consists of a cylindrical piece of Cobalt 60-doped plastic scintillator, 3 mm thick and 1.2 cm in diameter, which is seen by two 1.9 cm photomultipliers.

A gamma ray is electronically identified by a delayed coincidence between the D1 and D2 detectors, combined with the absence of a veto from all charged particle shields and from the calibration detectors. The quantities measured for each event are:

- the energy of the Compton electron in D1 (energy >50 keV)
- the location of the collision in D1
- the pulse shape of the scintillation pulse in D1
- the energy loss in D2 (energy >500 keV)
- the location of the interaction in D2
- the time-of-flight of the scattered gamma ray from D1 to D2
- the absolute time of the event

The pulse shape measurements and the time-of-flight measurements are performed in order to reject background events.

A gamma-ray event is initially selected according to coarse criteria established on the pulse heights of signals from D1 and D2, time of flight, the absence of a veto signal from all anticoincidence domes, and the provision that no preceding interaction has deposited a large amount of energy in the triggered cell (overloads). If the initial event selection logic is satisfied, a series of actions is initiated as follows: (1) pulse height analysis of the 15 photomultipliers of the identified modules of D1 and D2, plus the sum of the eight D1 and seven D2 PMTs; (2) time-to-digital conversion of the time-of-flight and pulse-shape discriminator circuit outputs; (3) the triggering of the digital electronics; and (4) the sampling of the event time. In addition to this normal double-scattering measuring mode, two of the NaI crystals of the telescope will be used to measure the energy spectra of cosmic gamma-ray bursts and solar flares.

The digital outputs of the pulse height analyses and the time-of-flight conversions are further checked against upper and lower limits, pulse shape, and ratio of energy deposits, which are stored in the final gamma event selection logic via serial telecommands. The data are stored in the event buffer, with those events satisfying the final selection criteria having first priority and those failing one or more criteria having second priority for transmission through the telemetry. Calibration data are transmitted regularly either as events or as spectra.

Estimates of the orbital trigger rate and the need to transmit an adequate sample of calibration events have led to an event message rate of 48 events per 2.048 seconds. For one event, 16 x 16 bit words are required. COMPTEL's data rate is thus 6125 bits/sec.

The Energetic Gamma-Ray Experiment Telescope (EGRET)

(a) EGRET Instrument Objectives

The principal objective of the EGRET experiment is high sensitivity observations of the gamma-ray sky in the energy range from 20 MeV to 30,000 MeV (30 GeV). It will have the best angular resolution of any of the GRO instruments and will provide good energy resolution.

The high energy telescope will be able to recognize point sources that are nearly two orders of magnitude fainter than the Crab nebula. For strong sources the position should be determined to about 10 arcminutes, and the strongest high energy sources should be identified with a positional accuracy of 5 arcminutes. Spectra should be measurable over the entire energy range for the stronger sources.

For the diffuse galactic plane emission, the spectrum will be measured with high accuracy, and spatial variations in the spectrum should be measurable on a scale of a few degrees. Features which subtend more than about 0.5° will be resolvable as extended sources. The diffuse radiation away from the galactic plane will be separable into galactic and extragalactic components on a scale of about 5°. The extragalactic component will be studied for spatial variations in intensity and spectrum.

(b) EGRET Instrumentation

The telescope is shown schematically in Figure 8. The directional telescope consists of two levels of a four by four scintillator array with selected elements of each array in a time-of-flight coincidence. The upper spark chamber assembly consists of 28 spark chamber modules interleaved with 27 tantalum plates, each with a 0.02 radiation length (which is a function of the energy of the radiation and the type of material) in which the gamma-ray may convert into an electron pair; the initial direction of the electrons may be determined from their tracks in the spark chamber. The lower spark chamber assembly (between the two time-of-flight scintillator planes), allows the electron trajectories to be followed, provides further information on the division of energy between the electrons, and permits seeing the separation of the two particles for very high energy gamma rays. The energy of a gamma-ray will usually be determined from measurements made in the Total Absorption Shower Counter (TASC), a 76 cm x 76 cm NaI(Tl) scintillator crystal eight radiation lengths thick located below the lower time-of-flight scintillator plane.

A gamma-ray entering the telescope within the acceptance angle has a known probability of converting into an electron-positron pair in one of the thin metal foils between the spark chambers in the upper portion of the telescope. If at least one of the electrons is detected by the directional time-of-flight coincidence system as a downward moving particle, and there is no signal in the large anticoincidence scintillator surrounding the upper portion of the telescope, the track imaging system is triggered, providing a digital picture of the gamma-ray event, and the analysis of the energy signal from the NaI(Tl) crystal is initiated. Incident charged particles are rejected by the anticoincidence dome. Low energy backward moving charged particles which do not reach the anticoincidence dome are rejected by the time-of-flight measurement. Events other than the desired gamma-rays, such as those gamma-rays interacting in the thin pressure vessel inside the anticoincidence scintillator, are rejected in the subsequent data analysis.

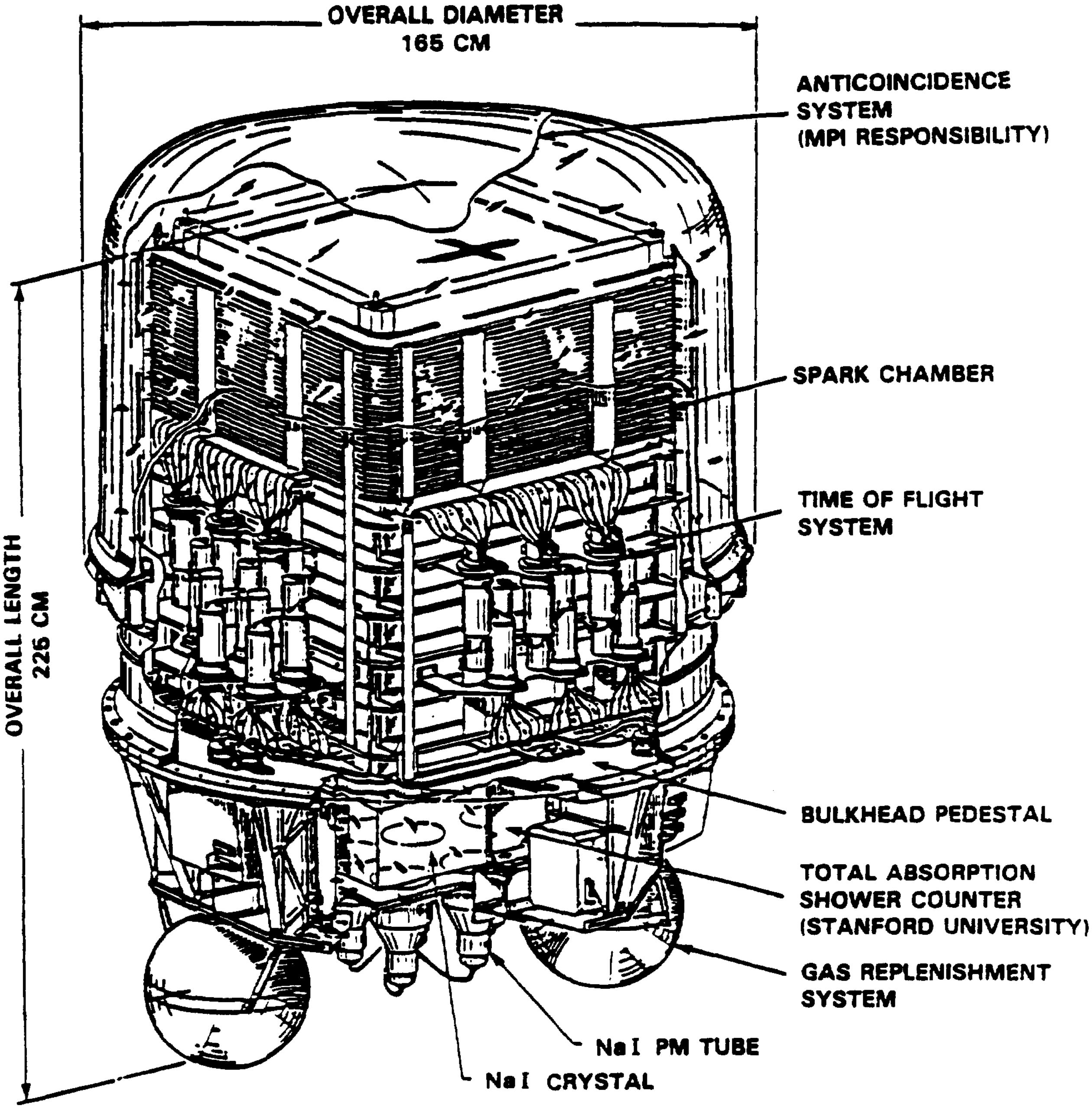


Figure 8. EGRET Detector Assembly

Gamma-ray bursts will be recorded in both the anticoincidence dome and the large NaI(Tl) crystal, where an energy spectrum measurement will also be made in the 0.6 to 140 MeV interval. After each burst trigger signal from BATSE, the spectra are recorded in four time intervals, which are preset between 0.125 and 16 seconds. Following the recording interval, the system is unable to recognize any additional BATSE triggers during the 35 minute readout period.

SPACECRAFT DESCRIPTION

Structure and Configuration

Figures 1 and 2, top and bottom views, schematically illustrate the configuration of the assembled spacecraft. With approximately 6000 kg of scientific payload, 8000 kg of spacecraft weight and 1900 kg of propellent, the total weight of GRO is about 15900 kg, GRO occupies about one-half the volume of the shuttle payload bay prior to deployment. Developed within the constraints and requirements of the National Space Transportation System (NSTS), the GRO structure accommodates the scientific instruments with an arrangement that provides unobstructed fields of view and supports all subsystem elements of the spacecraft. Figure 9 provides a break-away illustration of the platform, instrument adapters, and secondary structures. Three appendage structures — the high-gain antenna boom and the two solar arrays — are deployed while GRO is attached to the NSTS Remote Manipulator System (RMS).

Propulsion Subsystem

The GRO propulsion subsystem provides impulses for orbit altitude changes, orbit maintenance, attitude control, and controlled reentry. As schematically illustrated in Figure 10, the propulsion subsystem consists of the following major subassemblies:

- Four diaphragm propellant tanks capable of supplying up to a total of 1905 kg of hydrazine
- An Orbit Adjust Thruster Module (OATM) consisting of four 100 pound thrusters and isolation valves
- Four Dual Thruster Modules (DTMs) each consisting of two 5 pound thrusters for attitude control
- Two Propellant Distribution Modules (PDMs) containing the feed system filters, propellant pressure transducers, and latching isolation valves
- Two propellant/pressurant Fill and Drain Modules (FDMs)
- One On-Orbit Refueling Module (OORM) containing the JSC-supplied refueling coupler

The system operates in a blowdown mode over a pressure range of 2.76×10^7 to 5.79×10^6 dynes per square centimeter (400 to 84 psia). The propellant is high-purity monopropellant hydrazine and the pressurant is nitrogen. Crossover valves permit center of gravity management capability by controlling the quantity of propellant in each tank.

The four Orbit Adjust Thrusters (OATs) will be fired simultaneously to provide ΔV (change in velocity) impulses for orbit altitude changes as needed to maintain operational altitudes or for controlled reentry. The OATs are off-modulated to provide control about the roll and pitch axes during ΔV burns. The five pound Attitude Control Thrusters (ACTs) are canted from the Z-axis and fired in pairs to provide the necessary control torque about any of the three Observatory axes in the event of a failure in the primary or secondary attitude control modes.

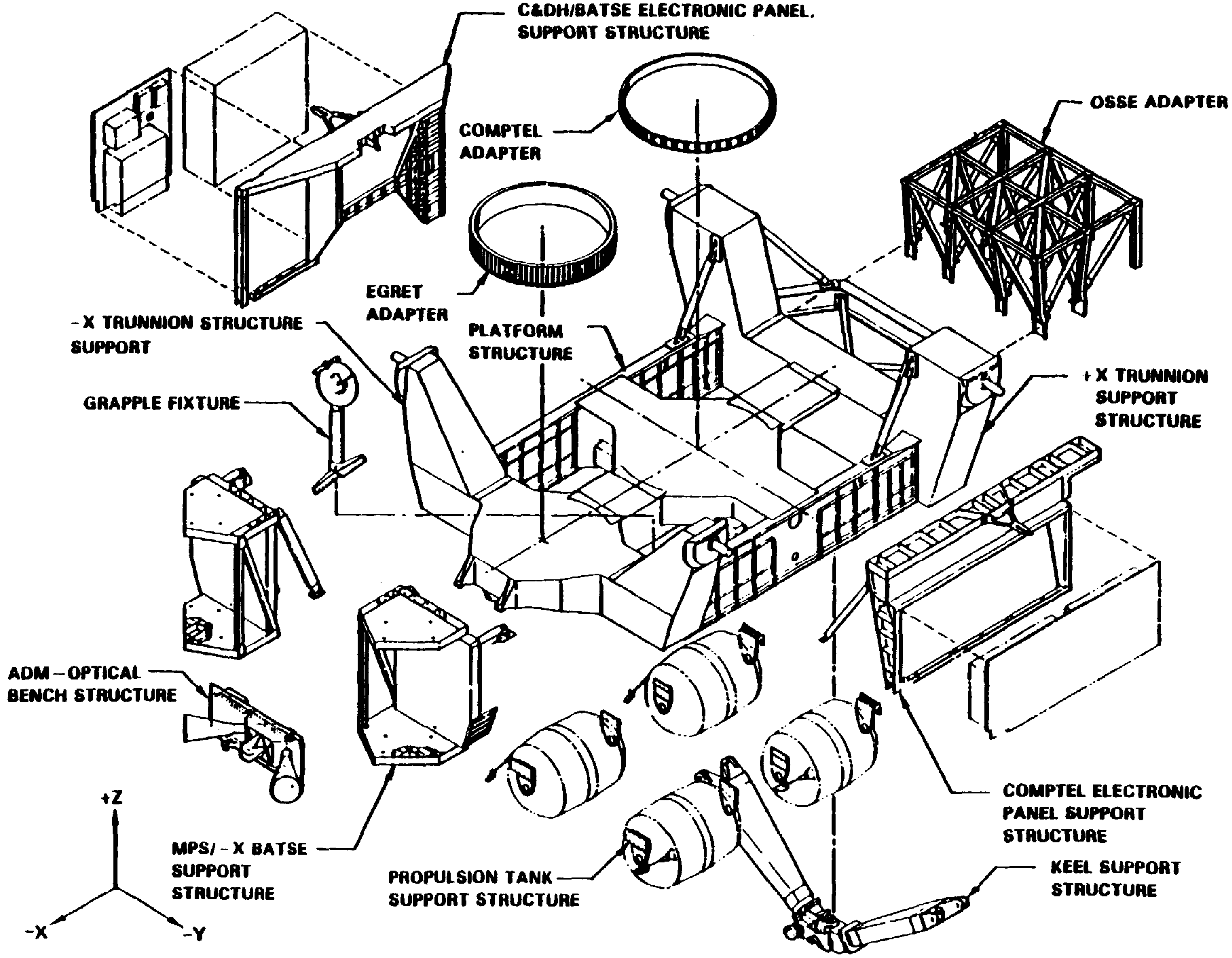


Figure 9. GRO Structural Elements

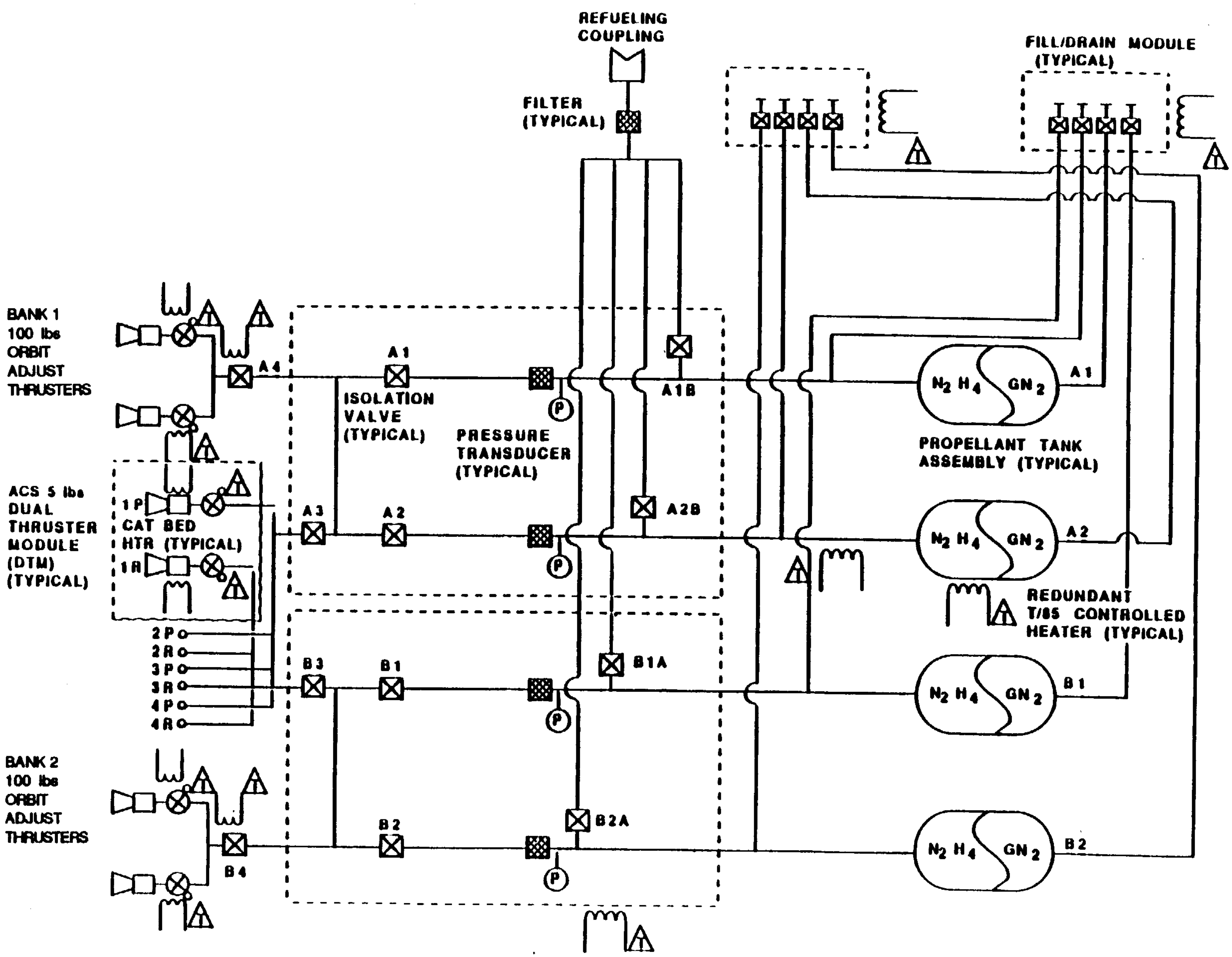


Figure 10. GRO Propulsion Feed System Schematic

Attitude Control and Determination Subsystem

The primary purpose of the Attitude Control and Determination (ACAD) subsystem is to point the GRO instruments to selected celestial gamma-ray sources and to supply attitude information for data processing. The ACAD subsystem is a three-axis system made up of many NASA standard components, together with other flight-proven hardware. A block diagram of the ACAD subsystem is shown in Figure 11. The sensors are shown on the left, the processing and distribution electronics in the middle, and the actuators on the right. The primary sensors are the Fixed-Head Star Trackers (FHST) and the Inertial Reference Unit (IRU). Other sensors include the Three-Axis Magnetometer (TAM), Fine Sun Sensor Assembly (FSSA), and Coarse Sun Sensor Assembly (CSSA). The prime actuators are the four skewed Reaction Wheel Assemblies (RWAs) that are unloaded by the Magnetic Torquer Assembly (MTA) or the ACTs in a backup mode. The Attitude Control Electronics (ACE) processes data from the sensors and sends it to the observatory's On-Board Computer (OBC) that is part of the Command and Data Handling (C&DH) subsystem. The primary control algorithms are located in the OBC. In the event of an OBC failure, the Control Processor Electronics (CPE) in the ACE processes the attitude data and drives the actuators. The ACE also acts as the interface to the C&DH system for commands and telemetry.

The Solar Array Drive Assembly (SADA) and the High-Gain Antenna Drive (HGAD) are also considered part of the ACAD system. The HGAD control signals are derived from the OBC that uses the Observatory attitude information and ground-supplied Observatory and Tracking and Data Relay Satellite (TDRS) ephemeris data to compute the antenna position angles. The solar-array drive is nominally positioned at a fixed orientation every 14 days by ground commands. In the event of a failure, the solar-array drive uses CSSA data to drive the arrays to an index position to provide a sun-tracking mode.

The primary and backup modes of operation for the ACAD system are defined below.

(a) Standby Mode
The standby mode is used during deployment from the shuttle. Sensors and processing electronics are on, but all actuators are disabled.

(b) Normal Pointing Mode
The normal pointing mode provides the capability to point the GRO to an accuracy of 0.50 degree per axis in any orientation required for the science mission. The FHST and IRU provide attitude information to the OBC. The IRU gyros provide inertial rate data and the FHSTs perform star measurements for attitude and gyro drift updating. Torques for stabilization are provided by any three of the four reaction wheels. Three MTAs are driven for wheel momentum unloading. Earth magnetic field measurements are provided by the TAM.

(c) Normal Maneuver Mode
The normal maneuver mode allows holding attitude or maneuvering to any required orientation up to 180° in less than 1 hour. Control torques are provided by the Reaction Wheel Assemblies (RWAs). The only difference from the normal pointing mode is that the momentum unloading and gyro updating functions are disabled.

(d) Thruster Maneuver Mode
The thruster maneuver mode provides the capability to maneuver the Observatory through a 180° turn in inertial space in less than 30 minutes using the attitude control thrusters. The thruster pairs are fired sequentially to provide the required control torques about each axis.

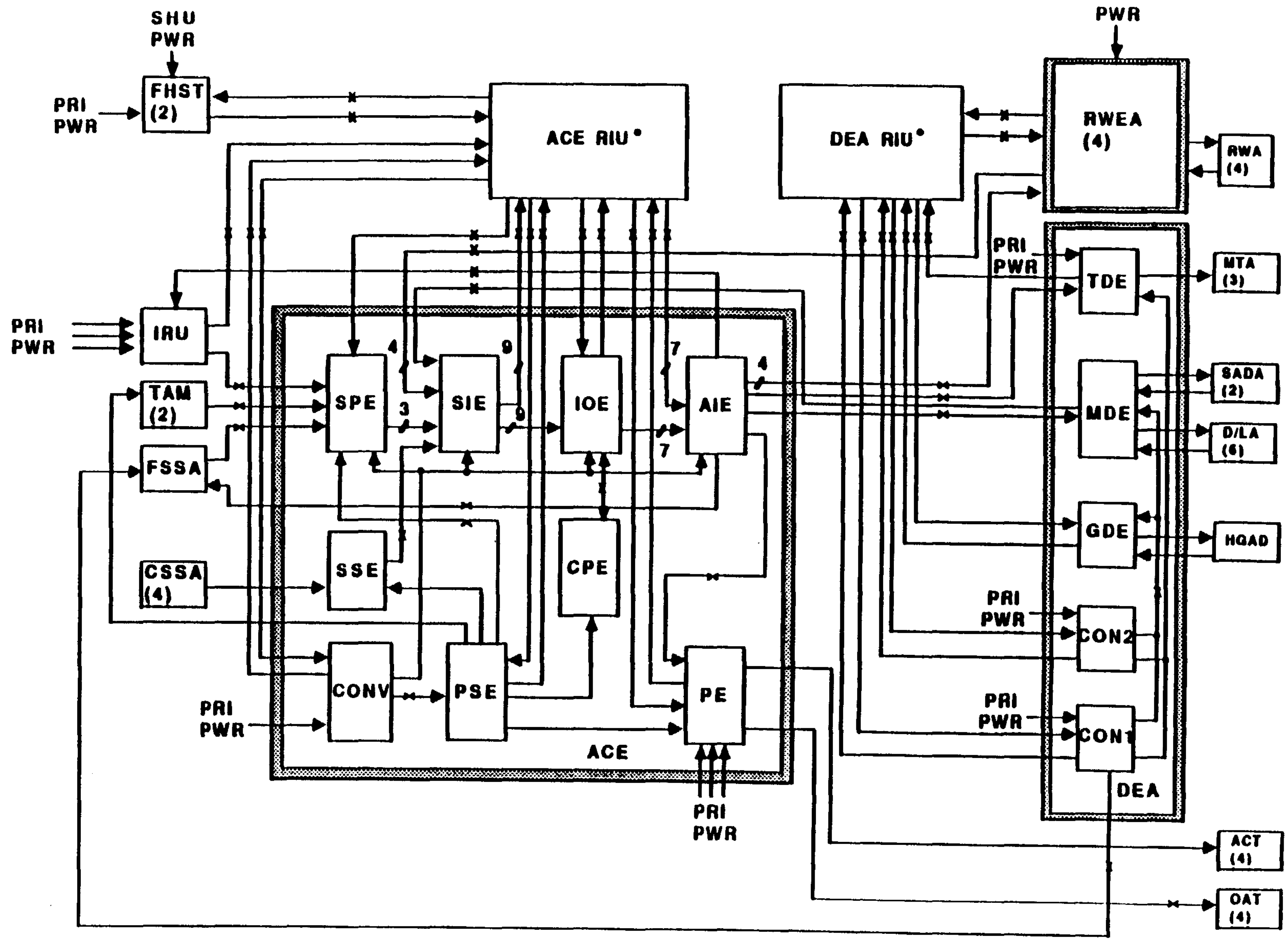


Figure 11. ACAD Block Diagram

(e) Velocity Control Mode
The velocity control mode provides the capability to execute velocity correction firings of durations selected by external commands. Control torques are developed by off-modulating the OATs and by firing the ACTs. The OATs can provide torques about the roll and pitch axes. The ACTs are used for yaw control.

(f) Sun-Referenced Pointing Mode
The Sun-Referenced Pointing Mode (SRPM) provides capabilities to hold attitude or to point the +X-axis at the Sun within 1.0 degree per axis using RWAs. The processing of attitude sensor data and control of the actuators is in the Control Processor Electronics (CPE) versus the OBC used in the normal pointing mode. An OBC failure is one way of getting into the SRPM. It can also be entered by ground command. Control laws are designed to operate with valid gyro data on at least two axes. In the event of bad data on either the pitch or yaw axis, rate data derived from the fine sun sensor can be used. In the event of a roll-axis IRU failure, the system operates on data provided by the fine sun sensor.

(g) Safe Hold Mode
The safe hold mode is a backup to the SRPM. If a failure occurs when in the SRPM, the Observatory will go to the safe hold mode. During this operation, the ACAD system will be capable of orienting and maintaining the X-axis within 6 degrees of the sun line. Starting from any orientation, this system is capable of reorienting the X-axis towards the sun in 30 minutes. Functions are identical to the SRPM except that the control torques are provided by the attitude control thrusters.

(h) Contingency Orbit Maintenance Mode
The contingency orbit maintenance mode provides the capability to change the orientation of the Observatory and perform velocity control firings without the OBC. Attitude control torques are provided by the ACTs.

Communications and Data Handling Subsystem

The Communications and Data Handling (C&DH) system, illustrated in Figure 12, provides the observatory's telecommunications and data processing functions. The C&DH design is based upon the standard NASA module used on the Solar Maximum Mission and Landsats 4 and 5. The C&DH module has been modified for use on GRO by the addition of a Time Transfer Unit (TTU) and the change to a packetized telemetry system. The C&DH subsystem consists of the C&DH module, a 60-inch high-gain antenna, two omni-directional low-gain antennas, and an RF combiner to interface the module with the antennas.

The C&DH module includes two second-generation TDRSS transponders for forward and return link transmissions to TDRSS, and for command and telemetry transmissions to the shuttle during the in-bay and deployment sequences. Redundant Central Units (CUs) for command decoding, telemetry collection, and formatting are provided. Two NASA standard tape recorders are included for data storage; each has the capability for storing 4.5 x 10^8 bits of data. Other components include redundant Premodulation Processors (PMP) for baseband signal formatting and mode selection; a NASA Standard Spacecraft Computer NSSC-1 OBC for attitude control, telemetry processing and monitoring, and command storage; and the TTU for correlating spacecraft time to Universal Time, Coordinated (UTC), and for distributing time to the four instruments. Timing accuracy is maintained to 0.1 ms by the use of the highly stable oscillator that controls the CU. A timing update

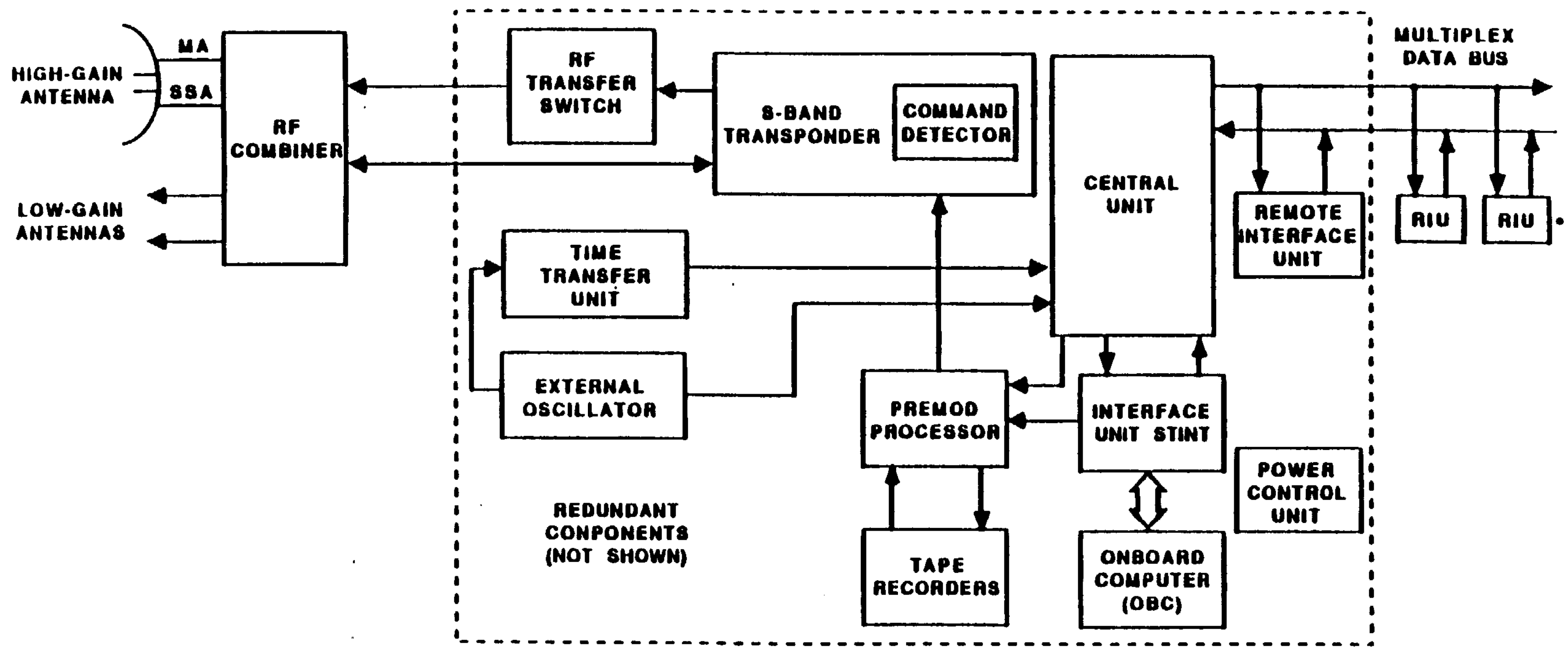


Figure 12. C&DH Subsystem Block Diagram

system at the TDRSS ground station is used to correct spacecraft time to 0.01 ms on a periodic basis.

Remote Interface Units (RIUs) are distributed throughout the Observatory to interface the instruments and other Observatory subsystems to the C&DH subsystem for command and telemetry transmissions. The CU sequentially interrogates the RIUs of each of the four science instruments to read out serially the formatted science data packets. Real-time data are transmitted through TDRSS at 32 kbps and the tape recorder dumps the data at 512 kbps every other orbit via the high gain antenna system and the TDRSS S-band Single Access (SSA) system.

Electrical Power Distribution Subsystem

The Electrical Power Distribution Subsystem (EPDS) generates, stores, conditions, and distributes primary electrical power to GRO. The subsystem components are two solar arrays, two Modular Power System (MPS) modules (Figure 13), an Electrical Integration Assembly (EIA), an Instrument Switching Unit (ISU), and an electrical interconnection harness and radio frequency (RF) cables. The EIA, ISU, and harness provide the function of power on/off, fuse protection, and distribution.

An array of silicon solar cells mounted on two wings provides primary power to the two MPS modules. Each MPS module provides power to a separate isolated primary bus and contains three nickel-cadmium (NiCd) batteries as secondary sources during nonilluminated periods. The MPS contains the electronic equipment necessary to condition solar array power to the required voltage range and to charge the batteries.

The Electrical Integration Assembly (EIA): (a) controls, protects, and distributes primary bus power to the spacecraft heaters and the ACAD subsystem; (b) processes its commands and provides status telemetry to the C&DH subsystem; (c) generates and distributes secondary power to the EIA itself, the ISU, and the propulsion pressure transducers; and (d) configures the propulsion subsystem isolation valves and provides command and safety telemetry interfaces to the launch vehicle.

The Instrument Switching Unit (ISU): (a) controls, protects, and distributes primary bus power to the instruments and spacecraft heaters; (b) processes its commands and provides status telemetry to the C&DH subsystem via interfaces located in the EIA; and (c) accepts secondary power from the EIA.

The interconnecting wire harness distributes primary power from the EIA and ISU and connects the EIA and ISU to the two MPS modules. Power, command and telemetry interfaces to the Orbiter and the Airborne Electrical Support Equipment (AESE) are provided via one power and one signal connector. RF cables provide signal connections between the RF combiner and each of the two low-gain antennas and one high-gain antenna and interface the RF combiner to the C&DH module.

The solar arrays will provide approximately 4000 watts when deployed after launch. The total power required for the Observatory is approximately 2000 watts. Each MPS module (Figure 13) conditions, regulates and controls solar-array power during the sunlight portions of the orbit to satisfy load demands and battery charging. During eclipse periods NiCd batteries supply the Observatory power. The batteries also supplement solar-array power during periods of peak power. Each MPS can receive power from external sources during ground operations and while in the shuttle payload bay.

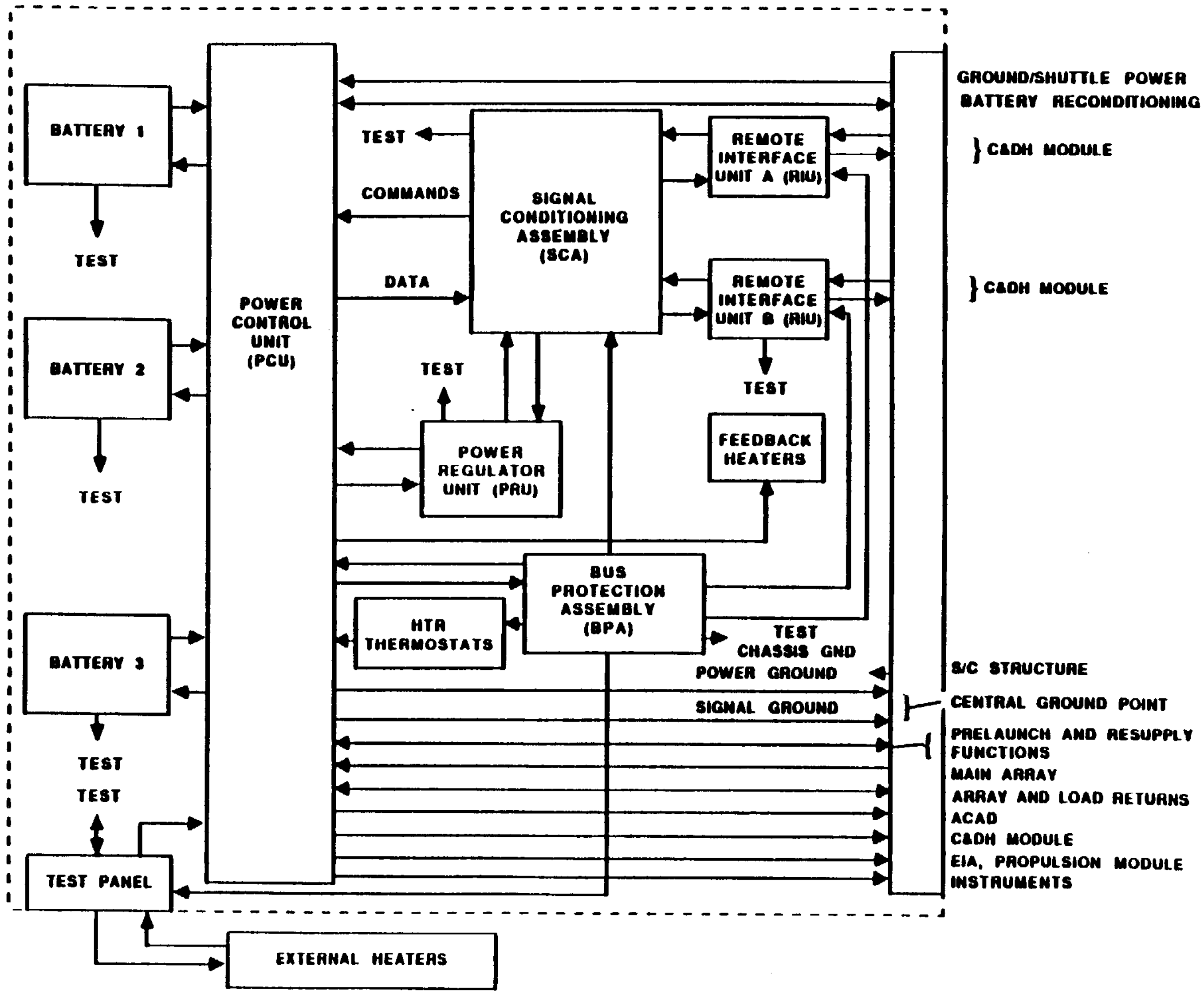


Figure 13. Modular Power System

Thermal Subsystems

The thermal control of subsystems and instruments is accomplished by appropriate use of coatings, blankets, louvers, radiators, and heaters. The instruments are thermally isolated from each other and from the spacecraft structure in order to reduce temperature gradients and to simplify thermal analysis and testing. The COMPTEL instrument uses variable-conductance heat pipes that transfer heat to a remote radiator in the hot case, while providing a near-adiabatic interface in the cold case. The other instruments have passive thermal designs.

GRO uses three groups of heaters, each having redundant thermostats and heater elements. Operational heater circuits are adequate for normal orbital operations in the coldest case. Make-up heaters replace the power of an instrument or component when it is turned off in orbit. Space Shuttle auxiliary heaters, powered through the AESE, are used to maintain temperatures while GRO is in the shuttle bay.

LAUNCH VEHICLE

GRO has been approved as a dedicated mission on the National Space Transportation System (NSTS). To maximize GRO's mission lifetime, the Orbiter will release GRO into a circular orbit at 450 km altitude and an orbital inclination of 28.5°. Prior to deployment, GRO, together with its associated Airborne Electrical Support Equipment (AESE) system, occupies approximately one-half the volume of the Orbiter payload bay.

Structural Interfaces

GRO is attached to the Orbiter via four sill and one keel trunnion fittings. The AESE system is installed in the bay forward of the GRO as illustrated in Figure 14. A Remote Manipulator System (RMS) grapple fixture is located on GRO (Figure 1) for deployment operations and for capture and handling during later missions. For repair and refueling missions, GRO has a refueling coupling and a flight support system berthing adapter and target. In addition, numerous handrails and foot restraint sockets have been installed to facilitate Extravehicular Activities (EVAs).

Electrical Interfaces

The AESE is used to power GRO auxiliary heaters to keep the Observatory thermally safe after the payload bay doors are opened, to provide limited alarm telemetry for monitoring critical parameters, and to power-up GRO for in-bay checkouts. GRO is electrically coupled to the shuttle via two Standard Umbilical Release System (SURS) connectors that are EVA rematable. The SURS connectors interface the GRO with the AESE, Standard Switch Panel (SSP), and T-0 umbilical. Selected GRO safety critical data are provided for display on board or at the Mission Control Center (MCC) and Payload Operations Control Center (POCC). GRO telemetry and command signals are routed to the ground via the shuttle Payload Interrogator/Payload Data Interleaver (PI/PDI) interface. (Communication with GRO is only possible when GRO is turned on for in-bay functional checks and RMS deployment operations.) Selected GRO telemetry is also displayed on board via decommutated data from the PDI. These same data are available via hardline whenever GRO is powered-up (either with the transmitter on or off).

For a refueling mission, GRO has an electrical interface installed beside the refueling coupling that provides pressure and temperature data on the refueling coupling and the GRO hydrazine propellant tanks.

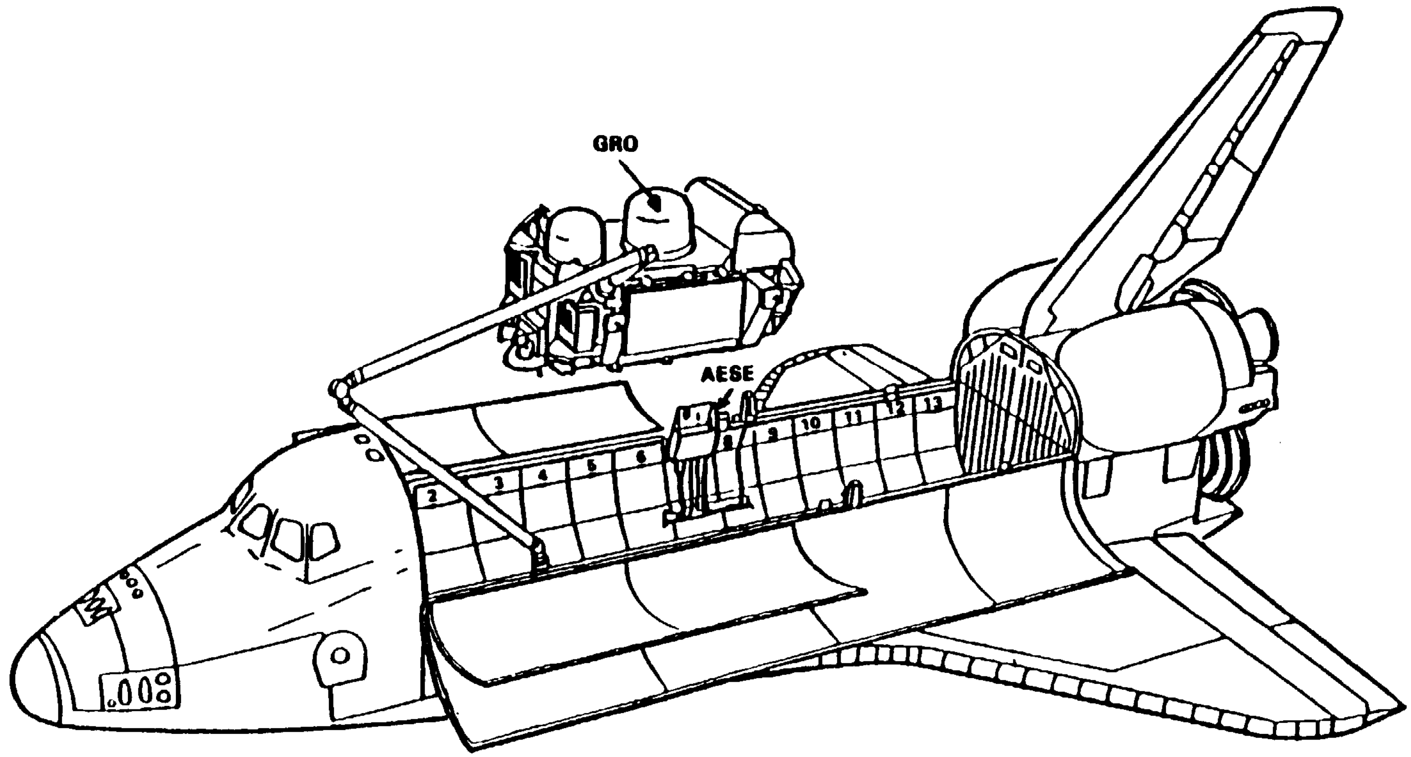


Figure 14. AESE Location in Payload Bay

MISSION SEQUENCE

Launch and Pre-Release Operations

The timeline in Figure 15 illustrates the sequence of GRO events prior to beginning the science mission. GRO is to be unpowered during the Shuttle's ascent phase except for power to keep the star tracker shutters in the closed position. GRO's Airborne Electrical Support Equipment (AESE) is to be powered-up by the Space Shuttle crew 1.5 hours after lift-off, immediately prior to the opening of the payload bay doors. The AESE power-up provides GRO with heater power and very limited alarm telemetry for monitoring critical parameters.

GRO's in-bay functional checkout (Figures 15 and 16) on Flight Day-2 is planned to start 21 hours after lift-off and lasts approximately 2 hours. These checks, performed by the Orbiter crew and the flight operations team at GSFC, include: (a) command and telemetry checks through the shuttle PI/PDI; (b) reaction wheel/attitude control system checks; and (c) direct telemetry and non-operational command checks through TDRS via the GRO omni antenna.

The power-up and communication aspects of the checkout also constitute a partial rehearsal for deployment activities on Flight Day-3.

The sequence of deployment activities, performed by the Space Shuttle crew and the flight operations team at GSFC on Flight Day-3, is illustrated in Figure 17. Figures 18 and 19, respectively, illustrate GRO's position on the Remote Manipulator System (RMS) prior to and after deployment of the solar arrays and the high-gain antenna. Contingency plans for appendage deployment failures require a quick-response EVA for manual deployment by the astronauts, if needed. The nominal deployment timeline (Figure 17) is designed to meet the following requirements and safety concerns:

- minimum power usage until arrays are charging
- Space Shuttle thrusters inhibited during unlatch and deploy
- temperature control of GRO solar arrays
- maintenance of two-fault tolerance for Space Shuttle safety
- daylight required prior to unberthing
- on-board sequences for uninterrupted actuations
- maximization of TDRS coverage for appendage deployment
- maximization of battery charging

Prior to release, dual telemetry links (Orbiter and TDRS) are to be established; however, no commanding via TDRS is planned prior to RMS release. GRO's batteries will go through a charging cycle prior to release such that the charge levels at release will allow one revolution with no solar illumination without exceeding a 67% depth-of-discharge limit. The nominal depth-of-discharge at release is 20% with a redline for release at 35%. Release plans call for a release at sunrise with the +X axis pointed at the sun and with maximum TDRS coverage. GRO is released in a free drift (standby) mode; the Orbiter will move away from the GRO after it has been released.

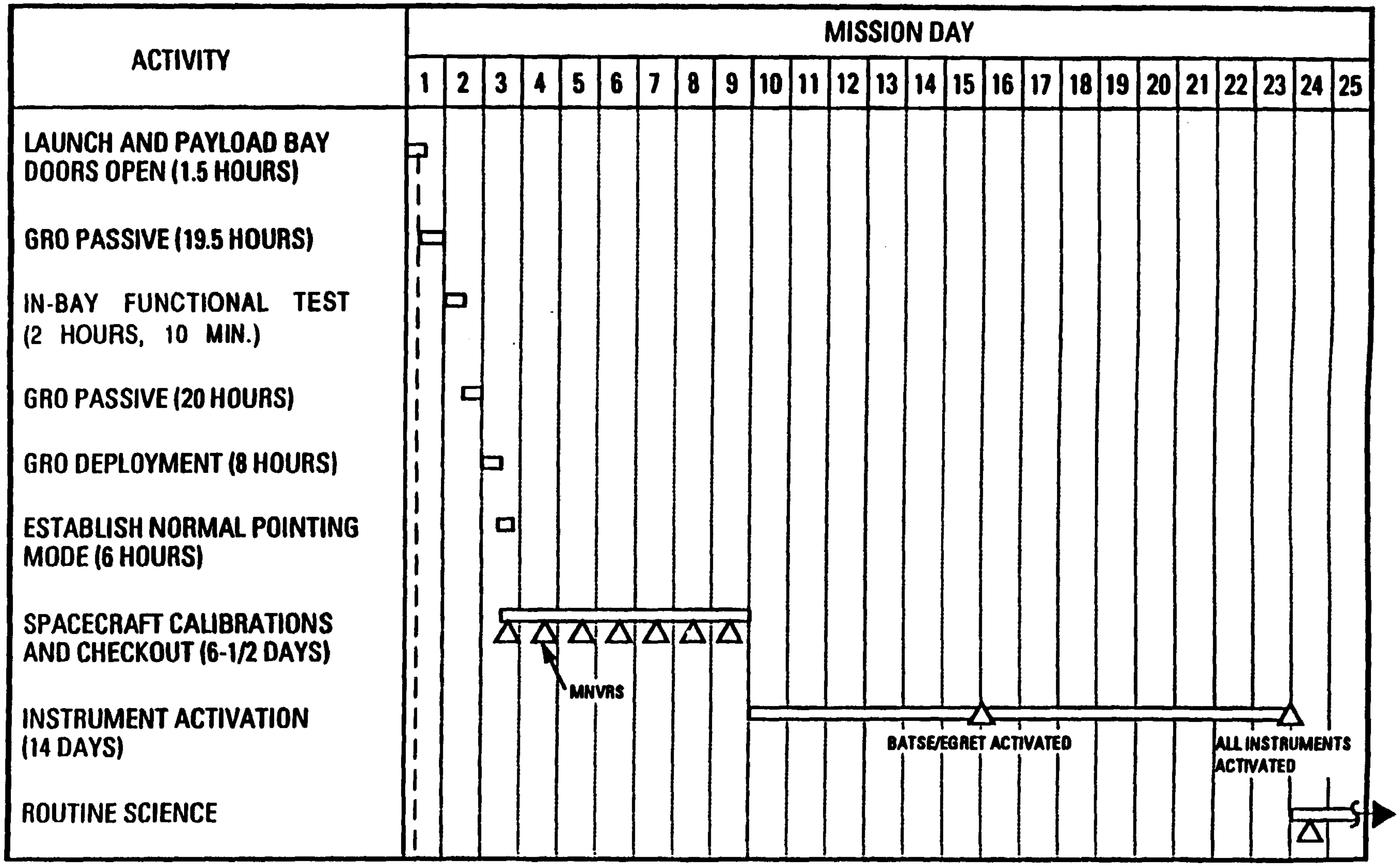


Figure 15. GRO Early Mission Timeline (Nominal)

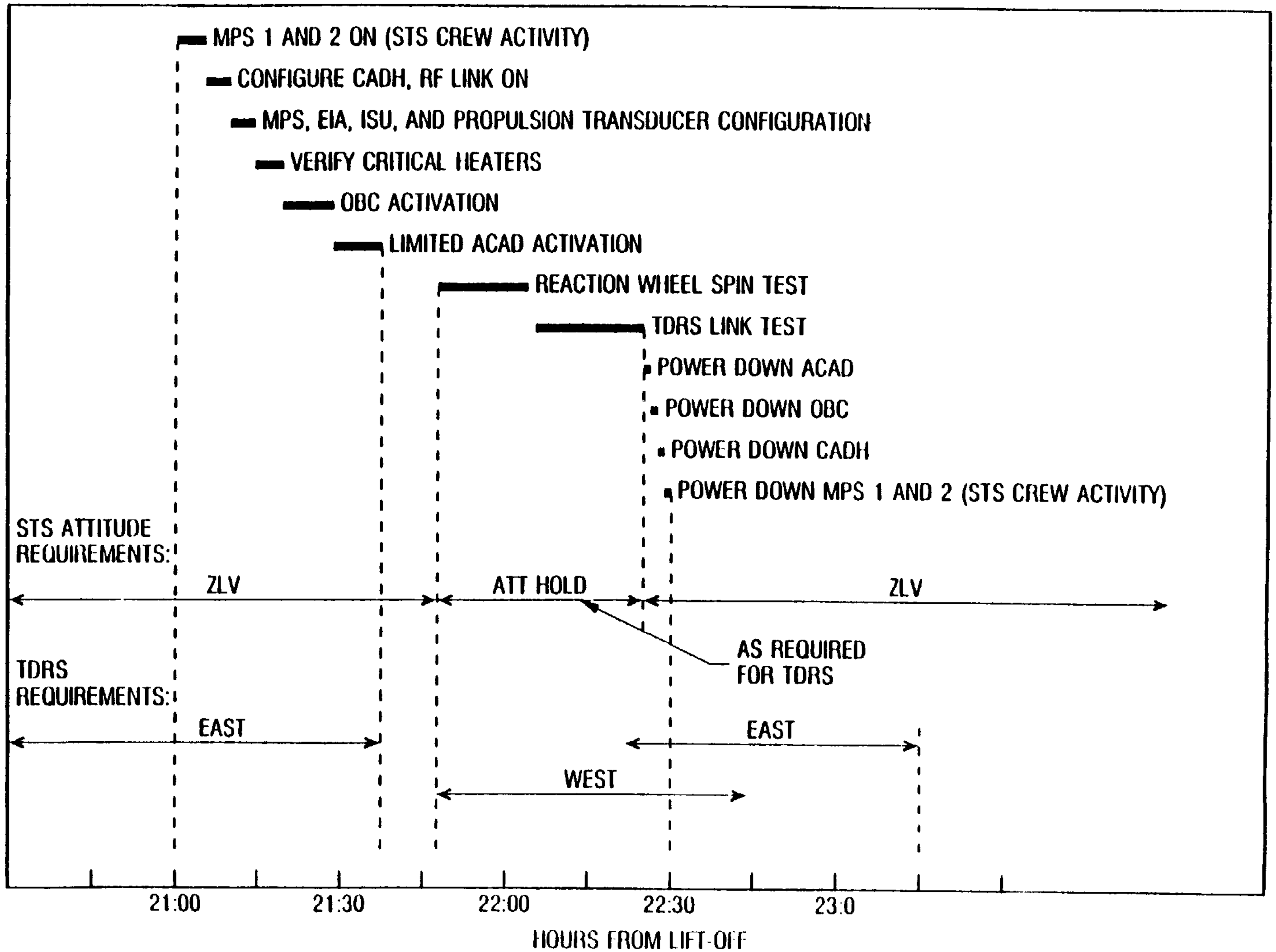


Figure 16. In-Bay Functional Checkout

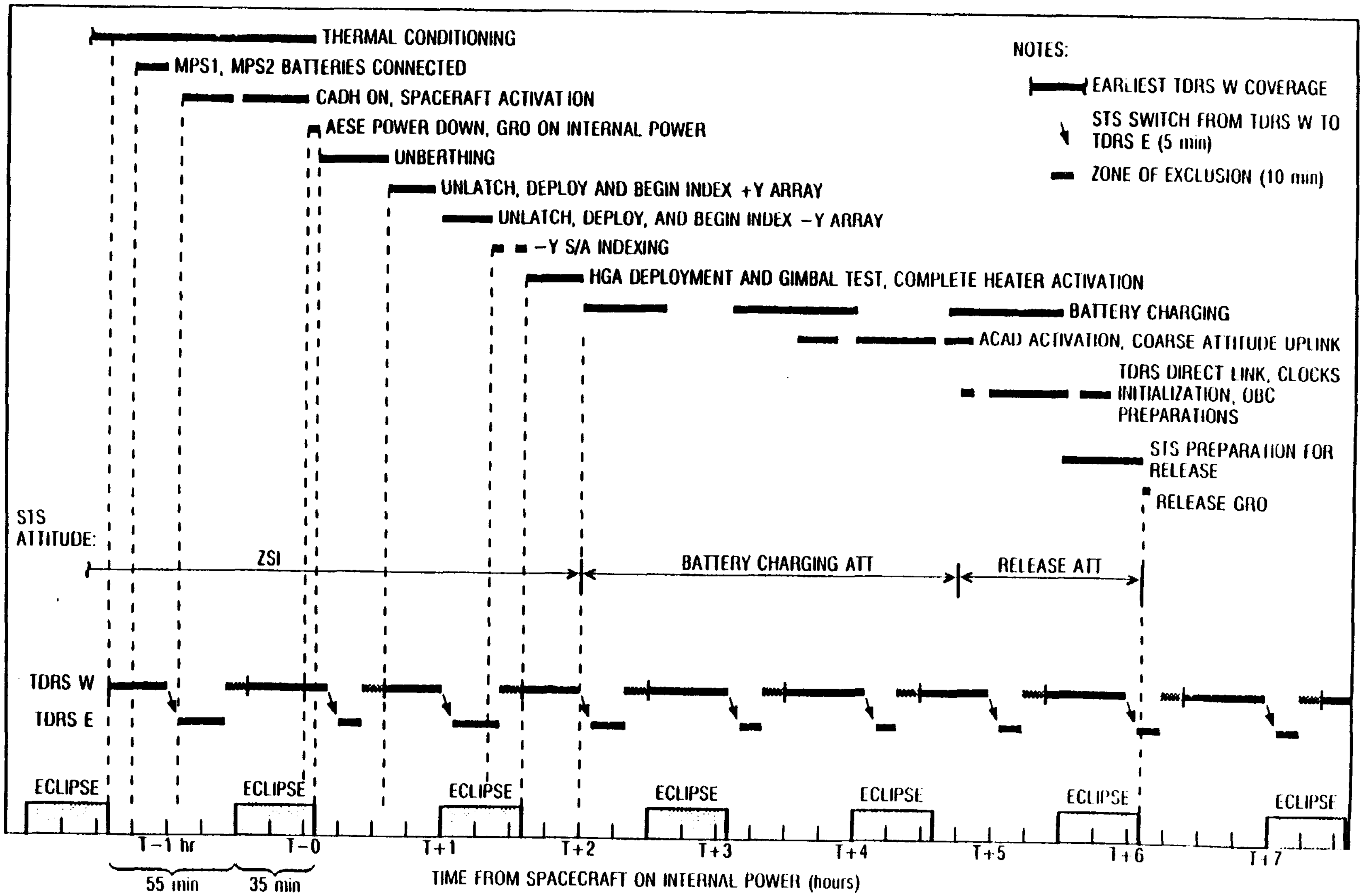


Figure 17. Deployment/Release Events

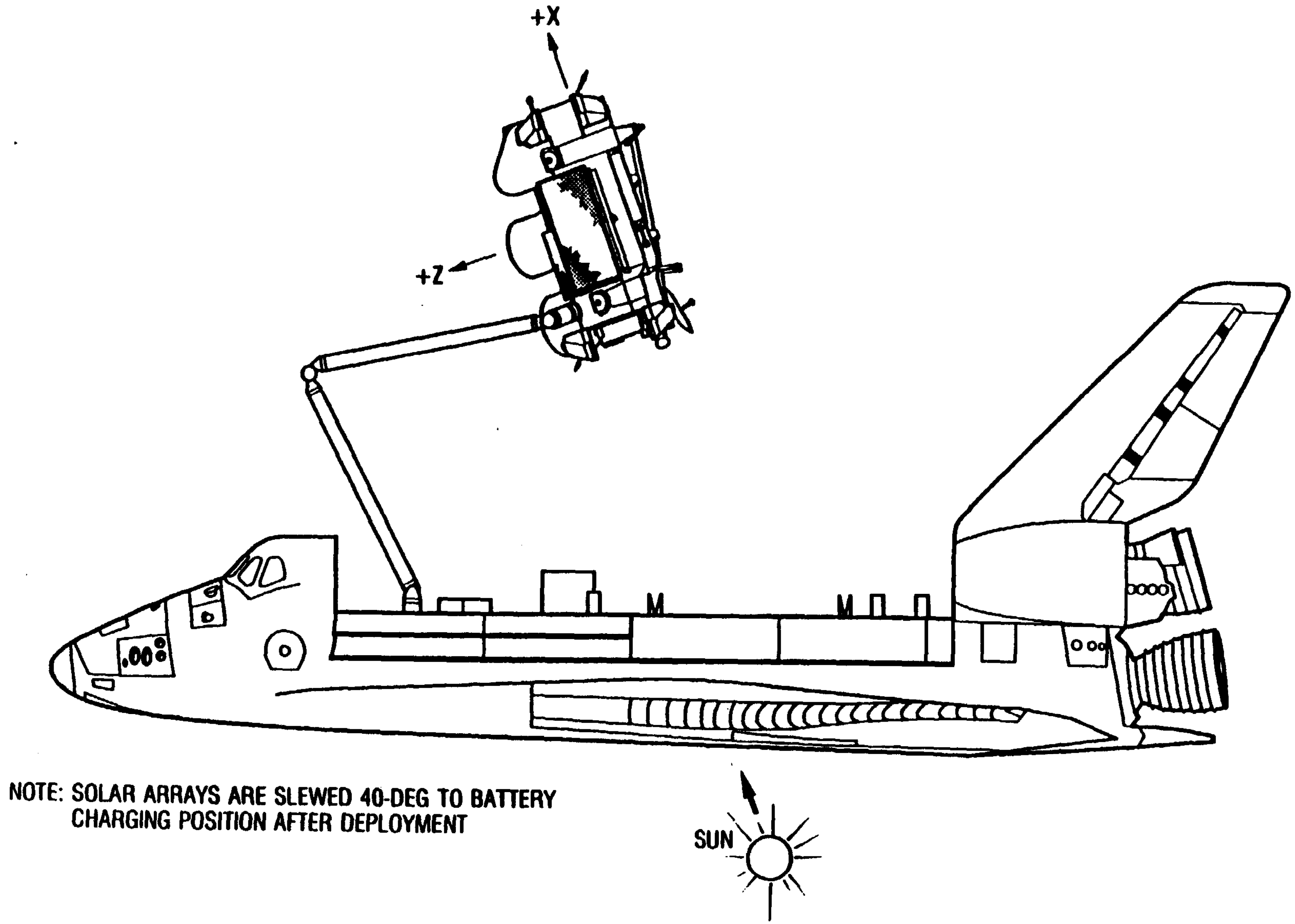
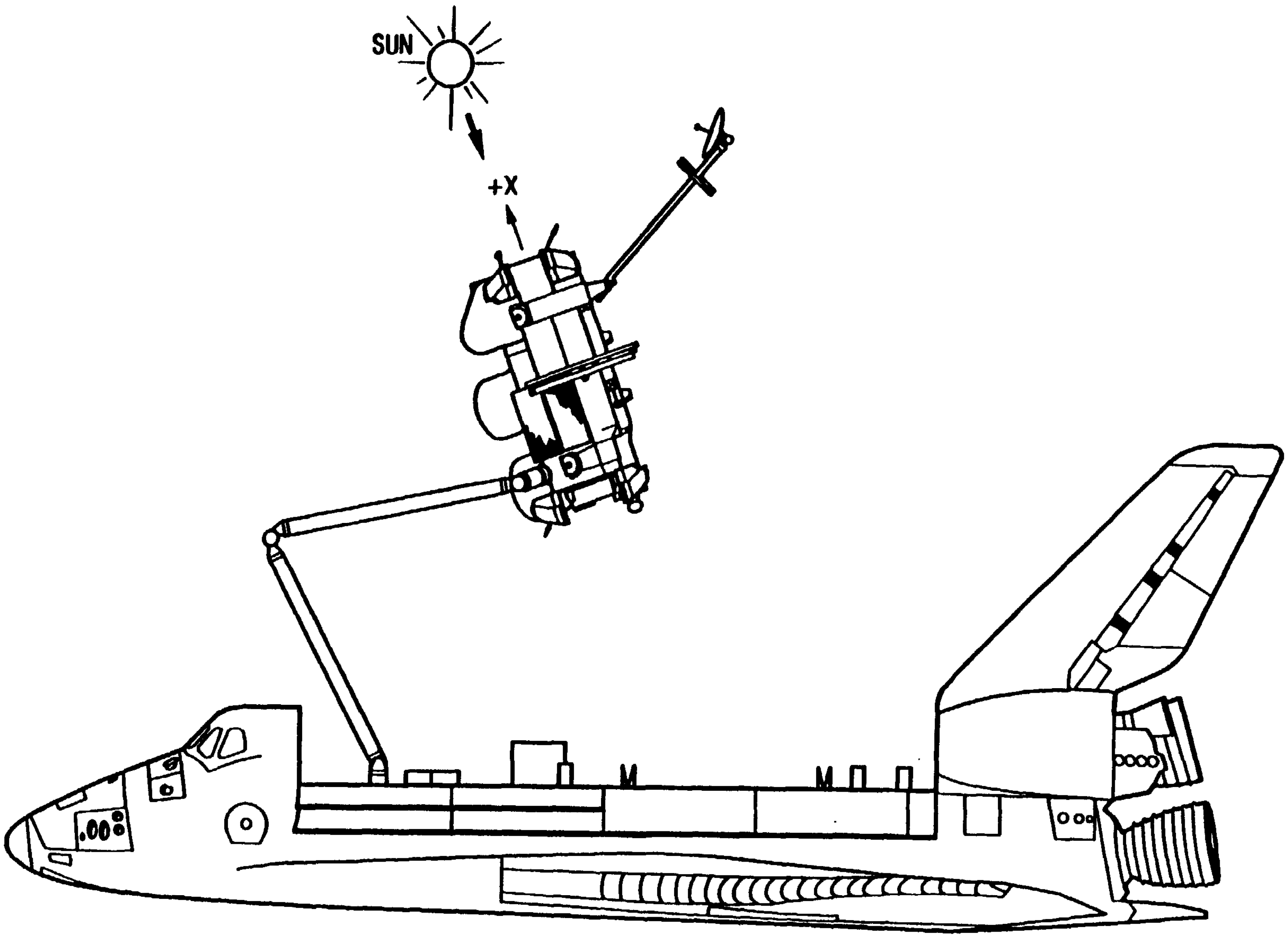


Figure 18. GRO Unberthing and Appendage Deployment



NOTES: 1. SOLAR ARRAYS ARE INDEXED JUST PRIOR TO ORBITER MANUEVER TO RELEASE POSITION
2. GRO IN THIS ATTITUDE NO MORE THAN 30 MINUTES

Figure 19. GRO Battery Charging and Release Attitude

Post-Release Activations

The 48-hour, Day-3 to Day-5, timeline for spacecraft activation (Figure 15) is illustrated in detail in Figure 20. The initial phase is used to check out the Observatory reference attitude control system. All spacecraft subsystems, except propulsion, are activated within 6 hours after release from the Orbiter. Following activation, routine tape recorder dumps via TDRS, each orbit or every other orbit, are initiated.

The daily timeline during the nominal 2-week period for activation of science instruments (Figure 15) is outlined in detail in Figure 21. Each of the four instruments is allocated 6 "clock" prime hours per day in which to command and observe activation operations. When not prime, each instrument can command on a non-interference basis. TDRS is required 30 minutes every orbit, thus each instrument will have 120 minutes during each six hour prime period in which to command. For the activation operations, the Instrument Ground Support Equipment (IGSE) for each instrument is located at GSFC and pre-canned activation sequences stored in the IGSEs or the Project Operations Control Center (POCC) are uplinked as directed by the instrument scientists. Typical timelines for major steps in activating and checking out each of the instruments are shown in Figure 22.

Routine Operations

GRO observing plans for the initial 15-month all-sky survey phase (see Figure 3 and previous "Observing Plan" section) call for pointing at each selected target continuously for 14 days before changing the Observatory attitude to point at the next target. A typical timeline for changing targets is illustrated in Figure 23 for a 180° attitude maneuver. When the orbit decays to an altitude of 440 km, an orbit adjust (ΔV) maneuver is to be executed to raise the altitude back to 450 km. A typical timeline for the ΔV maneuver is illustrated in Figure 24. The length of time between orbit adjustments depends on the atmospheric density which is a variable, dependent on solar activity. The pointing-maneuver sequence is schematically illustrated in Figure 25.

On-board tape recorded science and telemetry data are to be played back routinely via the TDRS S-band Single Access (SSA) link every other orbit. Stored commands and GRO and TDRS ephemerides will typically be uplinked via TDRS once per day. GRO has the capacity to store a maximum of 36 hours of commands and 48 hours of ephemeris data.

Mission Options and Termination

GRO's operational lifetime is anticipated to be 6 to 10 years without refueling of its onboard propulsion system. The current plan is to complete the mission with a controlled reentry into a defined area of the Pacific Ocean using GRO's onboard propulsion. However, capabilities to exercise other options have been designed into GRO. These include on-orbit repair and/or refueling, and retrieval for return to earth by the Orbiter. These scenarios are illustrated in Figures 25 and 26.

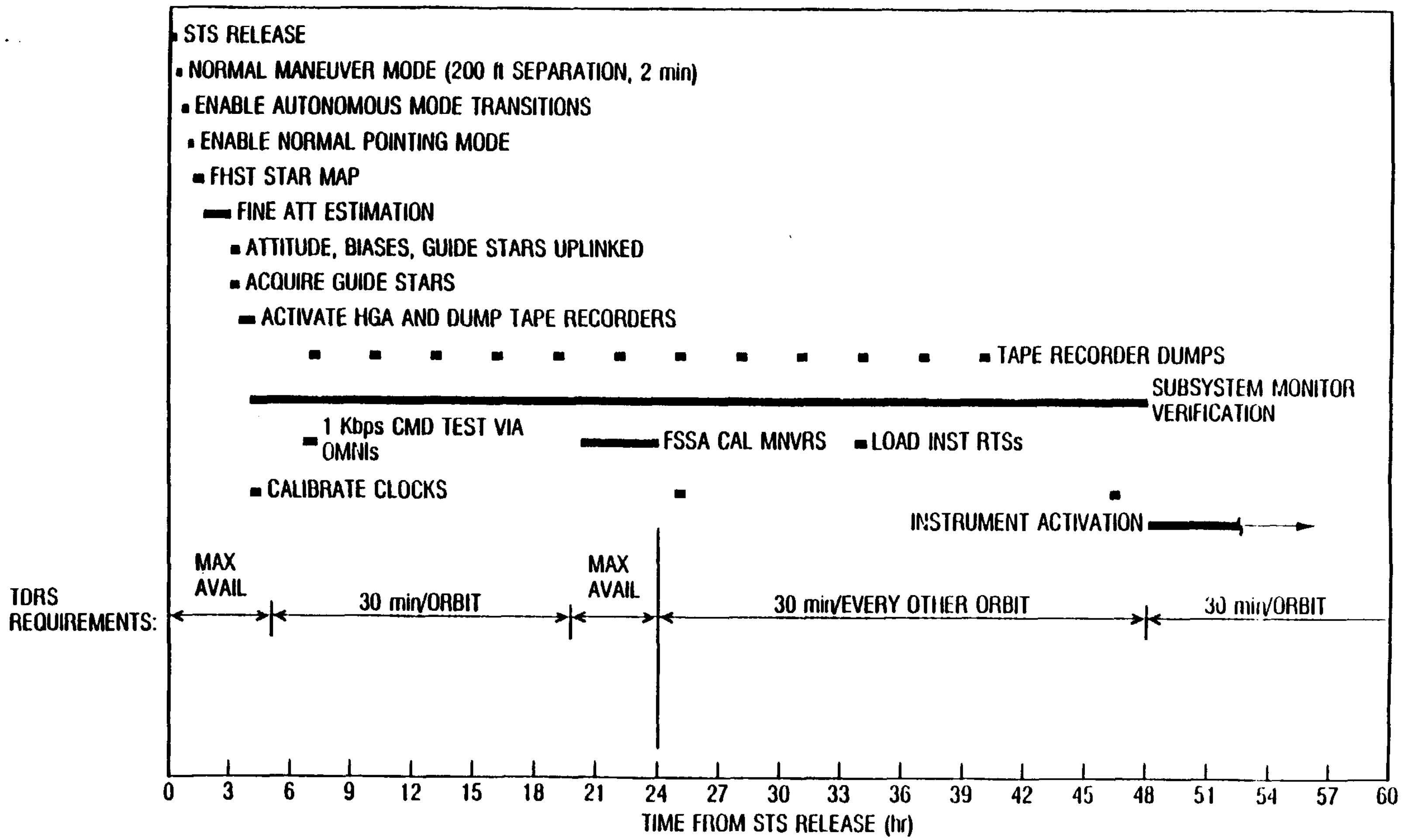


Figure 20. Spacecraft Activation Timeline

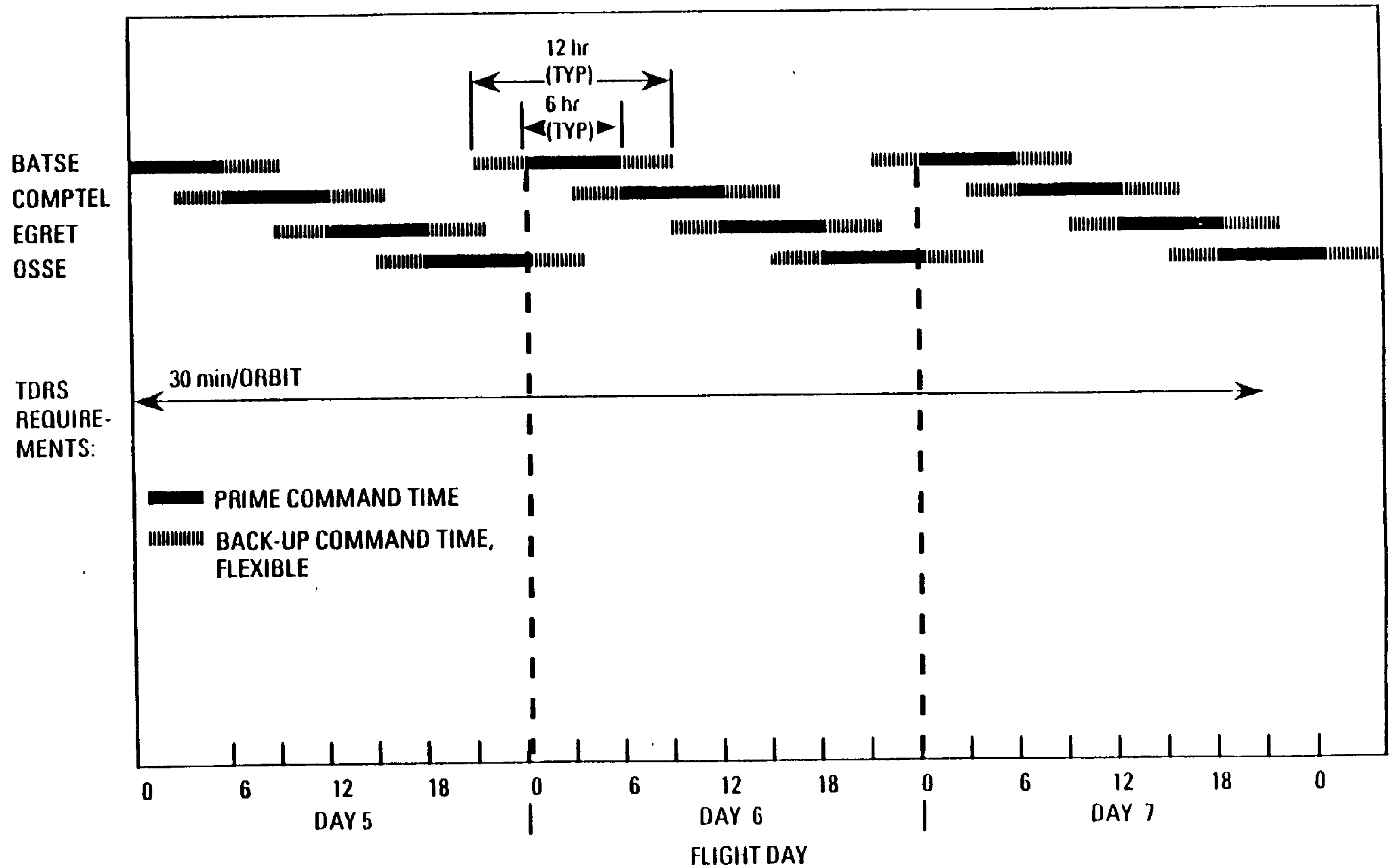


Figure 21. Instrument Activation

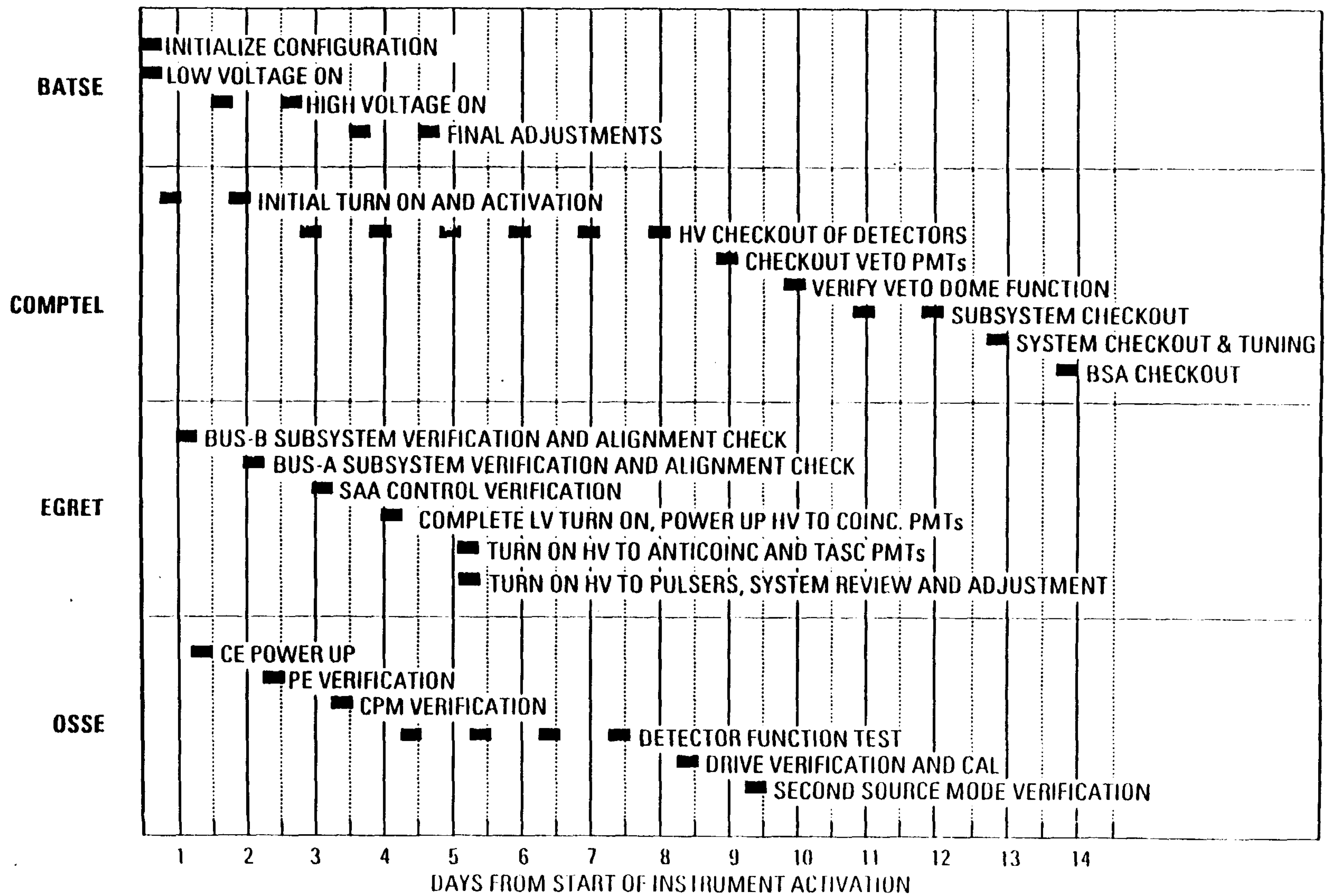


Figure 22. Typical Instrument Activation Timeline

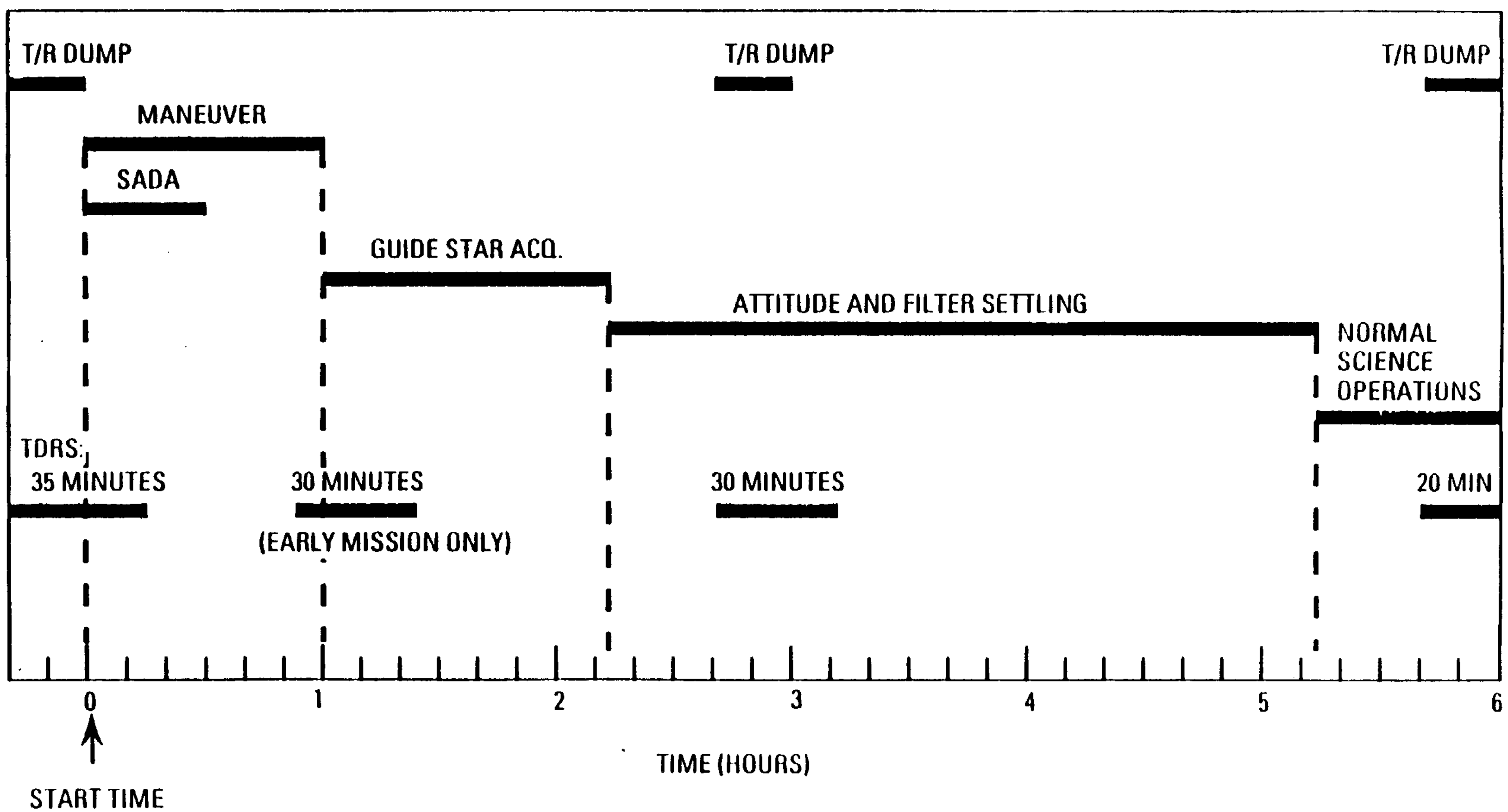


Figure 23. Timeline and TDRS Coverage for 180-Degree Attitude Maneuver

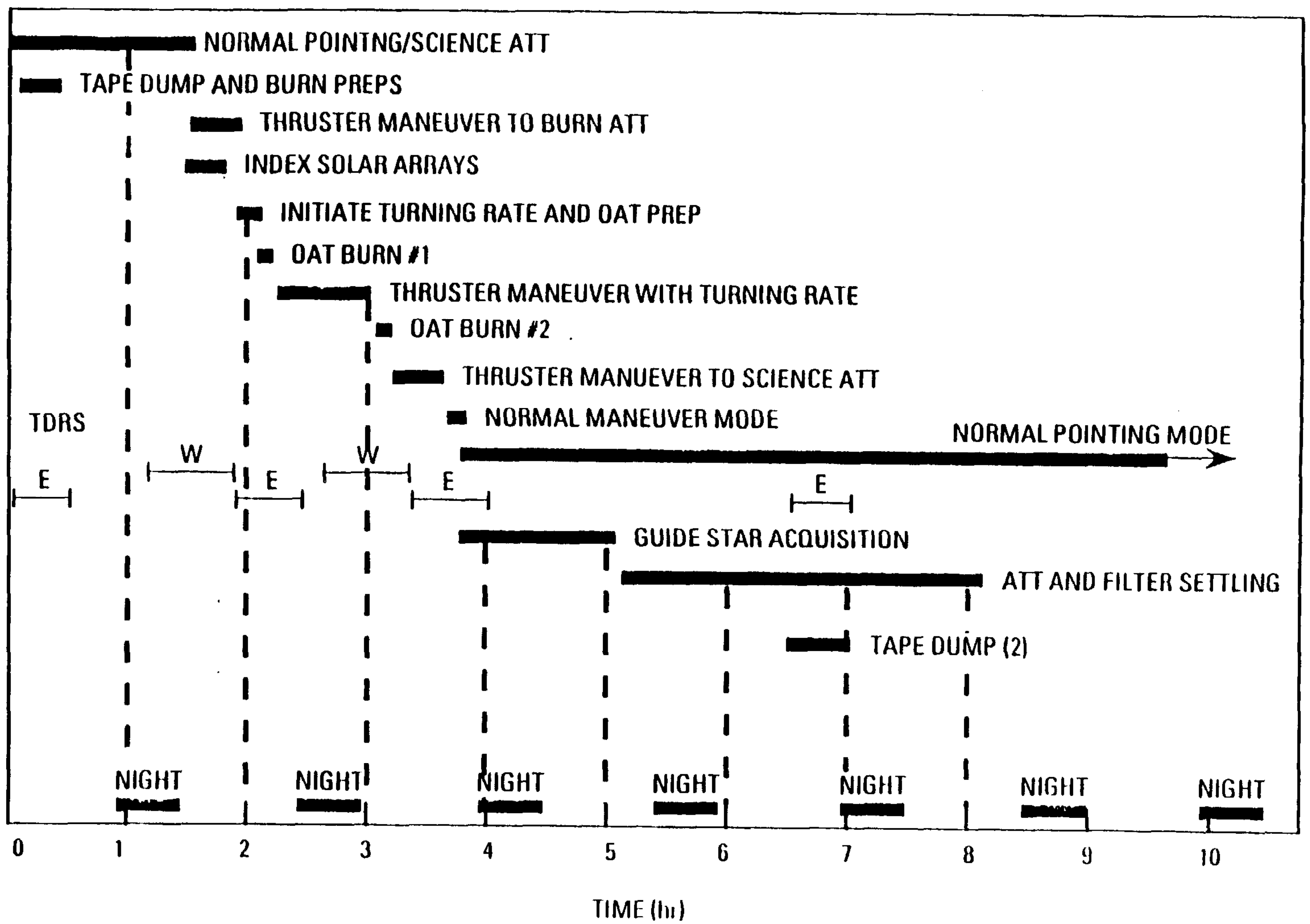


Figure 24. Delta-V Maneuvers

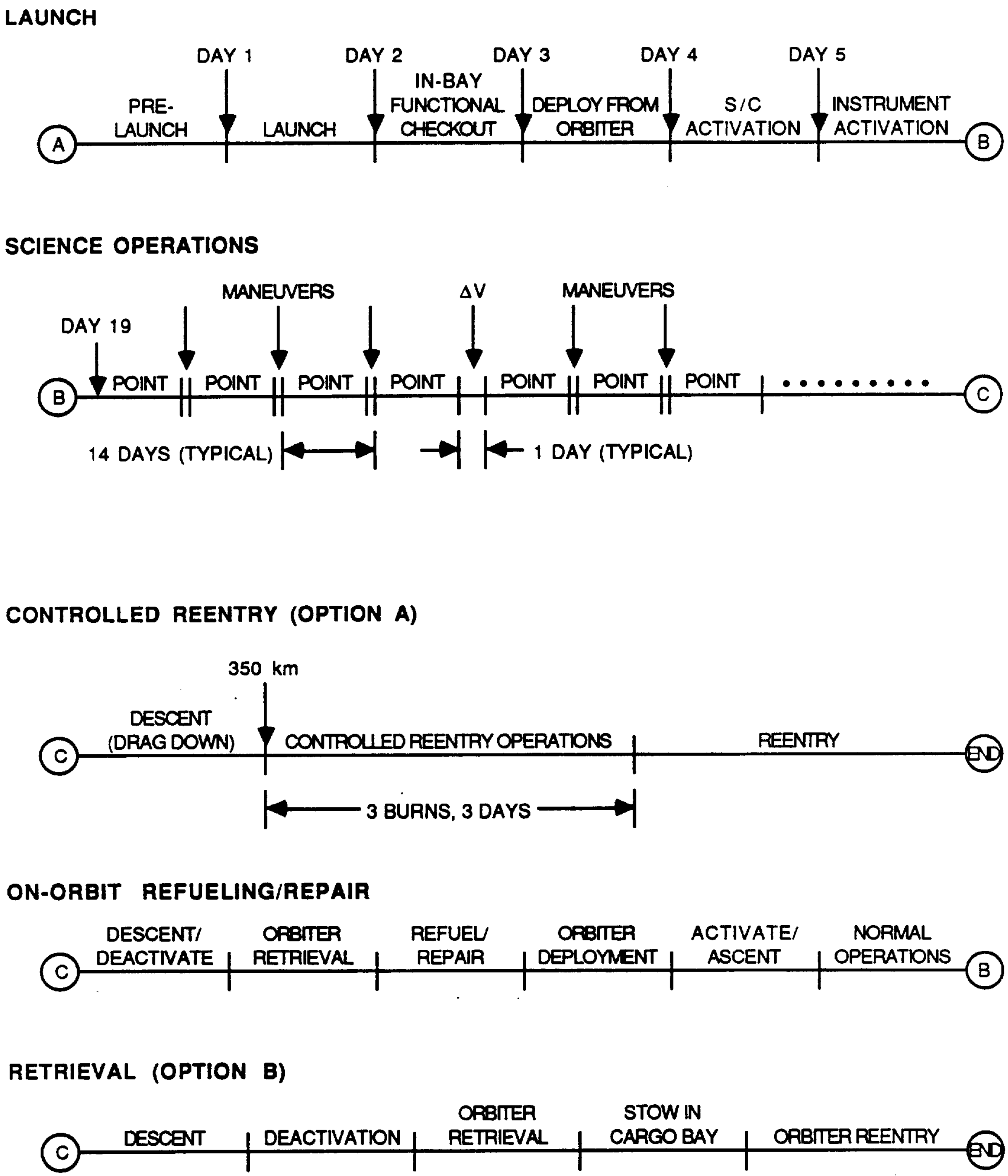


Figure 25. GRO Mission: Launch to Termination Stages

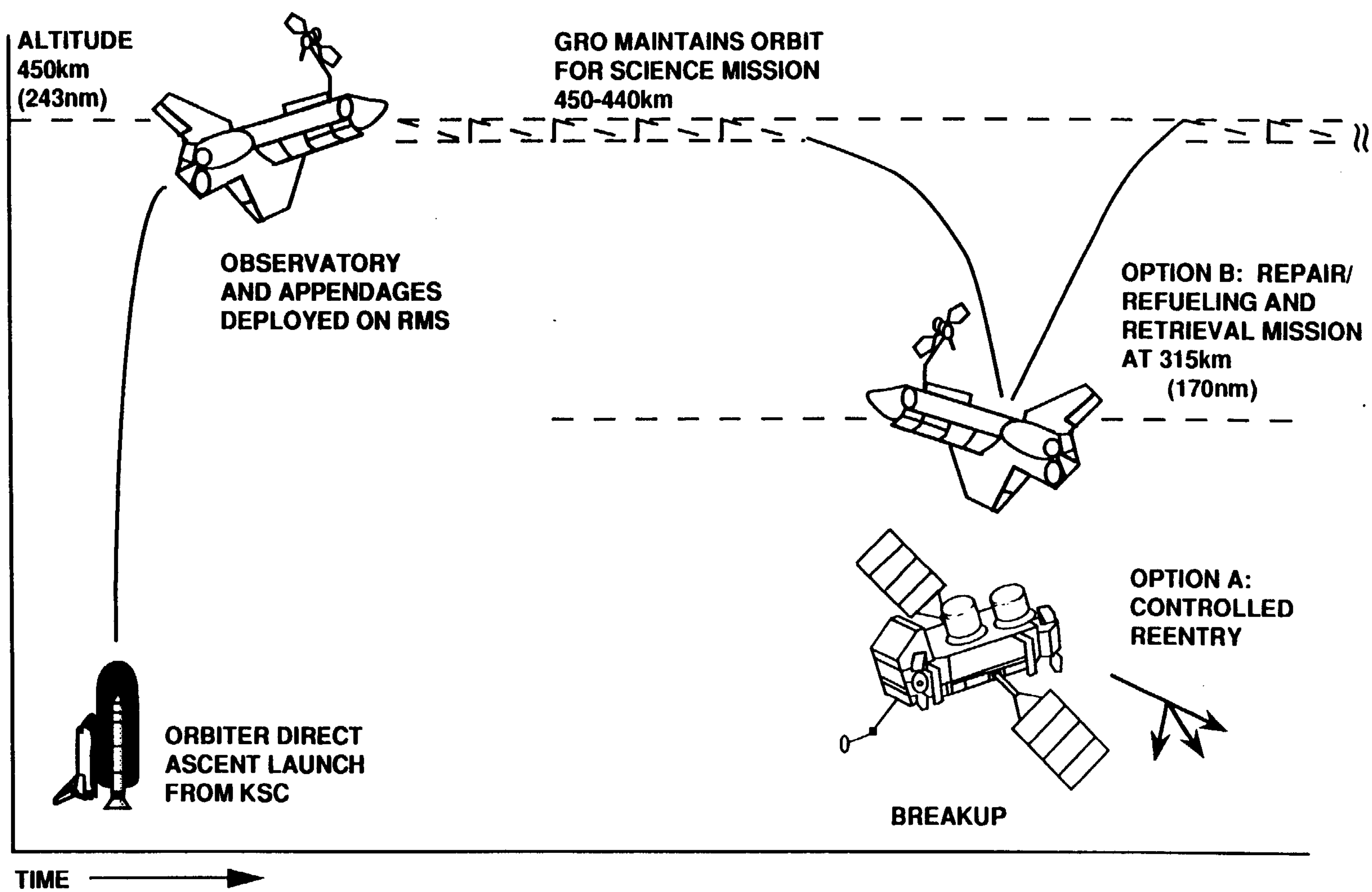


Figure 26. GRO Mission Options

MISSION SUPPORT

Ground Systems and Support Elements

The Mission Operations and Data Systems Directorate (MO&DSD) of the GSFC will provide the ground hardware and software used to support Observatory operations prior to launch and during the mission.

The GRO Project Operations Control Center (POCC) will be the focal point for all flight operations (Figure 27). The POCC is a part of MO&DSD's Multisatellite Operations Control Center (MSOCC). The MSOCC/POCC will provide mission scheduling, tracking, telemetry data acquisition, commands, and the processing required for display of down-linked data. A Mission Operations Room (MOR), staffed by the mission contractor's Flight Operations Team (FOT), is an integral part of the POCC. The FOT is responsible for all aspects of mission control (i.e., commanding, monitoring performance, data analysis, etc.) including spacecraft health and safety on a 24-hour basis. The MOR is equipped with interactive terminals, color graphic microprocessors, recorders, and closed circuit TV. This POCC arrangement interfaces with the MO&DSD facilities that provide command management, flight dynamics, and communications support.

The Command Management System (CMS) (Figure 27) is the ground software element that is the primary interface with the experimenters for receipt of Observatory commands. The CMS accepts spacecraft and instrument-stored command requests and On-Board Computer (OBC) memory loads, performs validity and constraint checks, and prepares the input for uplink by the POCC. The CMS interfaces with the experimenter's Instrument Ground Support Equipment (IGSE) via an X.25 communications network for command loads, the FOT for command verification, and the Flight Dynamics Facility (FDF) for OBC table loads and orbital data.

The Flight Dynamics Facility (FDF) (Figure 27) provides orbit determination information and support for network scheduling, OBC computation of orbit position, and onboard computation of the TDRS position. Orbit support also entails preparing plans for orbital maintenance and maneuvers, such as Delta V maneuvers and reentry/retrieval maneuvers. It also provides real-time and near real-time attitude determination support for all mission phases. This support includes attitude sensor calibration, bias computations, attitude related OBC memory load generation, and the monitoring of OBC attitude control performance. Lastly, the FDF provides a Viewing Support System (VSS) that will aid project analysts and scientists in constructing a viewing plan for celestial targets.

The Goddard GRO Simulator (GGS) (Figure 27) is a hardware and software system designed to model the Observatory in orbit and provide an interactive data source. It is used for validating POCC, OBC, and flight software, simulating Observatory performance including malfunctions and anomalies, and for training the FOT on Observatory operations.

The Network Control Center (NCC) (see Figure 27) processes the support requirements GRO places on the Space Network (SN) and the NASA Communications Network (NASCOM). The NCC will resolve schedule conflicts between projects requesting SN support.

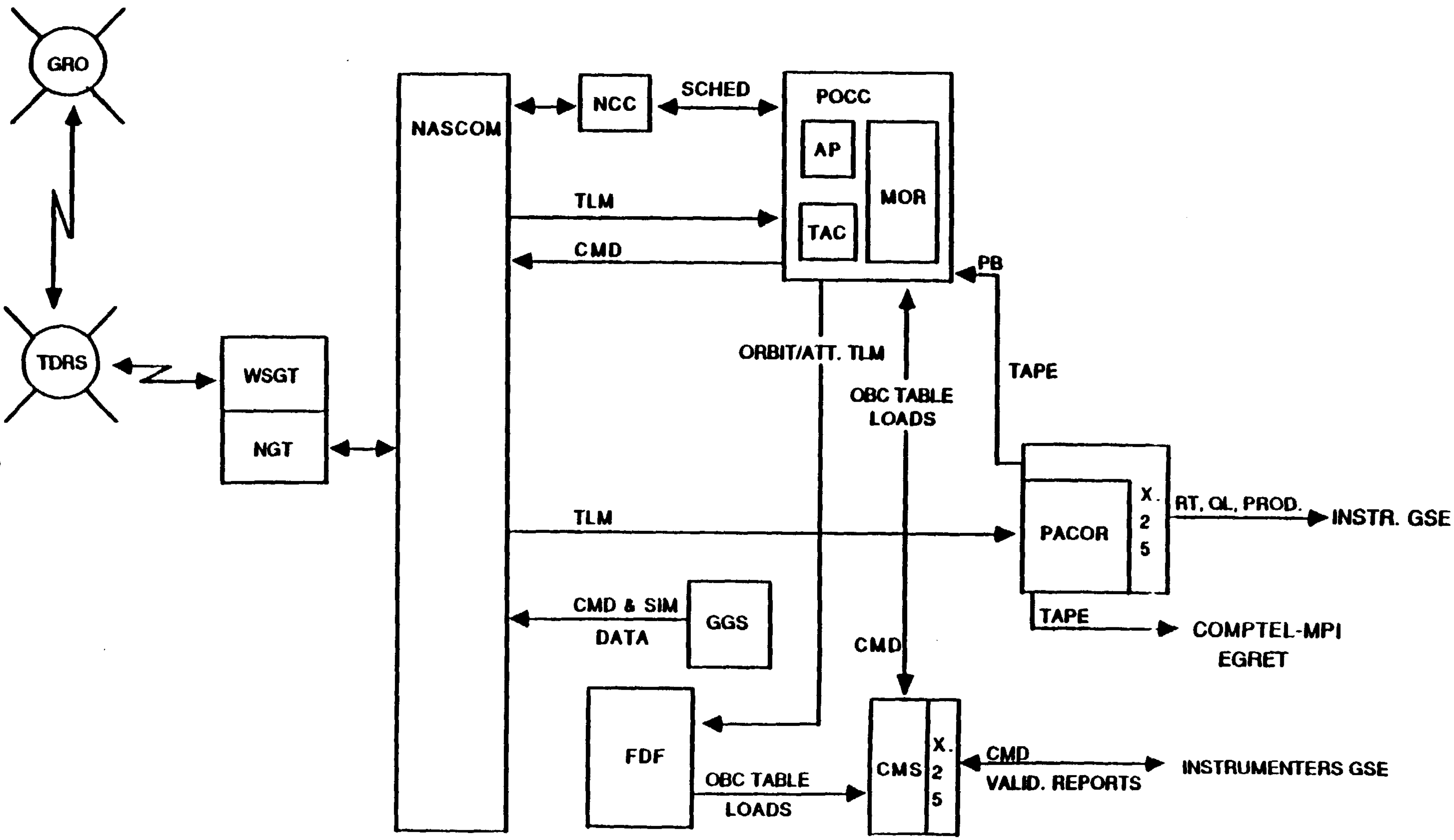


Figure 27. GRO Ground Systems and Flight Operations

Operational Data Flow

The command and telemetry communication links between GRO and the TDRSS and the associated antennas, carriers, and bit rates are illustrated in Figure 28. Figure 28 also illustrates the back-up support provided by the Deep Space Network (DSN) ground stations for launch and early orbit operations and emergencies. NASCOM provides the link between the TDRSS White Sands Ground Terminal and the GSFC ground systems, and the X.25 packet switching system for routing data via dedicated data lines. As shown in Figure 27, and simplified in Figure 29, telemetered real-time and playback GRO data go directly to two different MO&DSD facilities for processing: the POCC and the Packet Processor (PACOR) Data Capture Facility (DCF).

The POCC will process spacecraft engineering data and science housekeeping data for display in the MOR and will provide the FDF with telemetered spacecraft attitude data. The POCC will also compute spacecraft UTC time-correction data generated in the User Spacecraft Clock Calibration System (USCCS).

The PACOR/DCF will receive real-time and playback data in parallel with the POCC, and it will record, time order, quality check, and transmit the user sets of science data packets to the PI's data processing facilities via X.25 communications and/or on magnetic tape. The telemetry format is illustrated in Figure 30. The attitude, orbit, and time data required for processing scientific data is put into the secondary header of each packet on-board the Observatory. This eliminates the need for merging science data and the auxiliary orbit-attitude-time data on the ground and permits direct, unpacked transmission of the data package to the science investigators' data processing facilities. PACOR output products include:

- production data collected within one day that are sent within 48 hours to BATSE and OSSE via X.25 link
- production data collected within one day that are sent within one week via magnetic tape to EGRET and COMPTEL
- quick-look data sent within 2 to 6 hours via X.25 link to COMPTEL and OSSE
- real-time data sent within seconds via the X.25 link to COMPTEL and EGRET.

Quick-look data will consist of a contiguous two orbits of on-board recorder playback data selected by the experimenters 48 hours in advance.

Data Management

Because GRO was originally a Principal Investigator mission, data analysis and archival activities were conceived as four separate endeavors taking place at four separate geographical locations. However, since the extension of the GRO mission lifetime permitting the scientific involvement of a broader community through the Guest Investigator (GI) Program, GRO's data operations have been altered from a PI-oriented perspective to a user-oriented perspective. The individual data processing and management plans developed by each of the four instrument groups have accordingly been incorporated into a single GRO Project Data Management Plan (PDMP) and a GRO Science Support Center (SSC) has been established at GSFC to serve as a central point of contact with the scientific community.

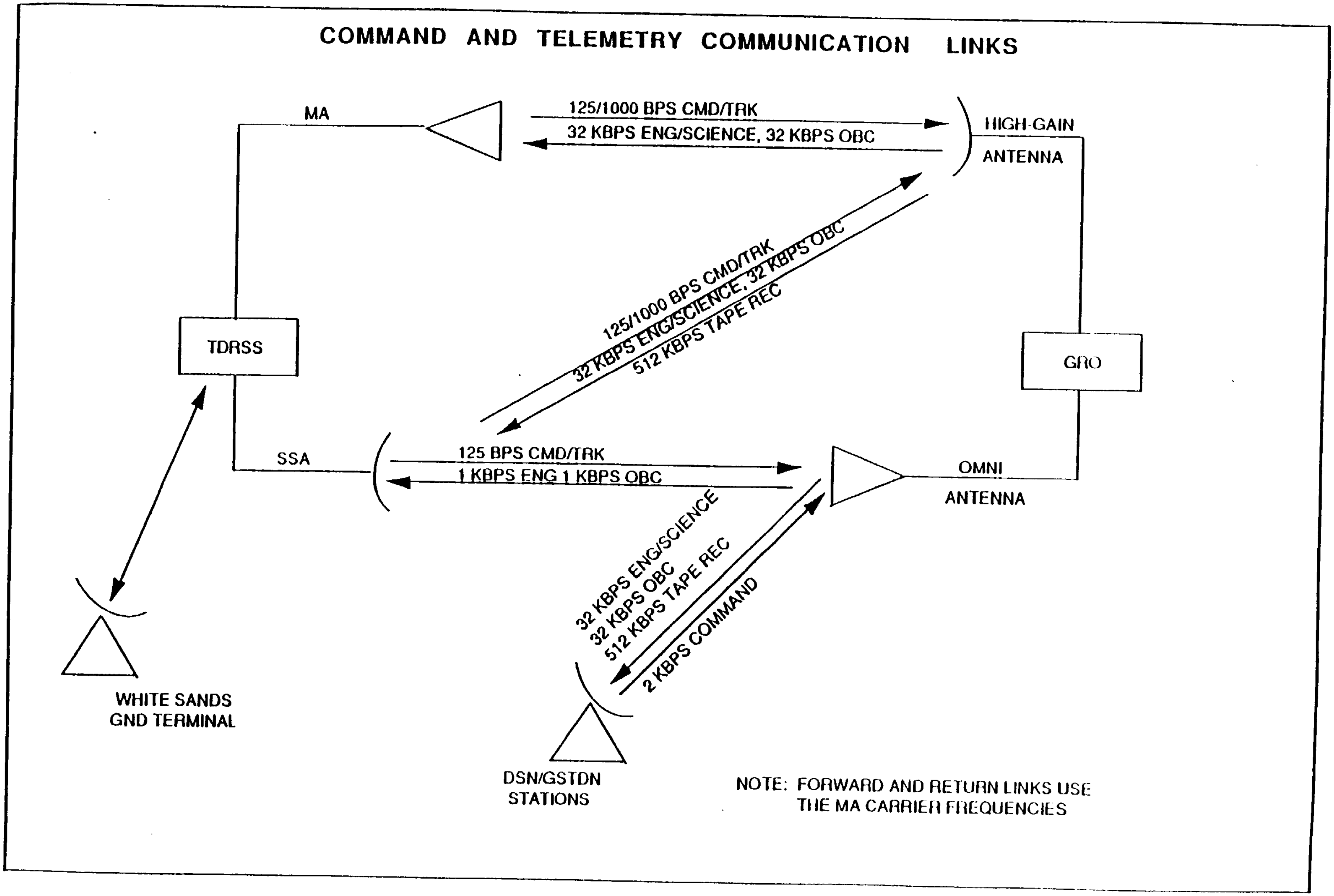


Figure 28. Command and Telemetry Communication Links

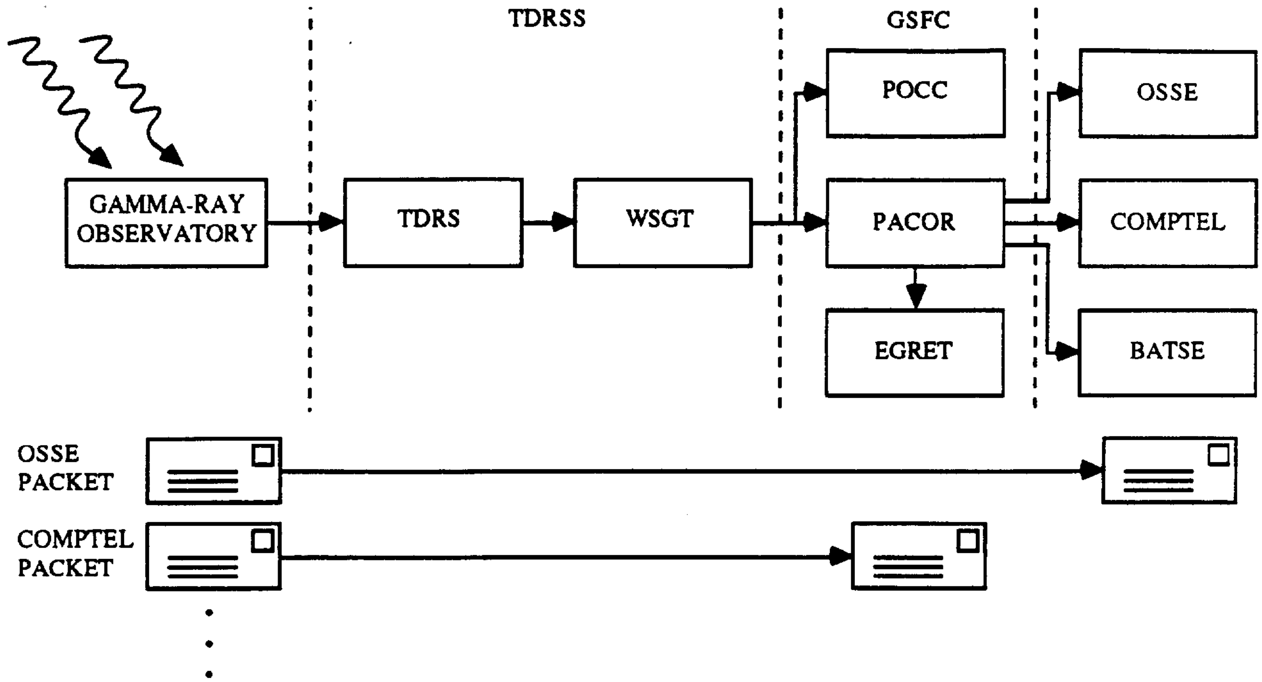


Figure 29. GRO Science Data Flow

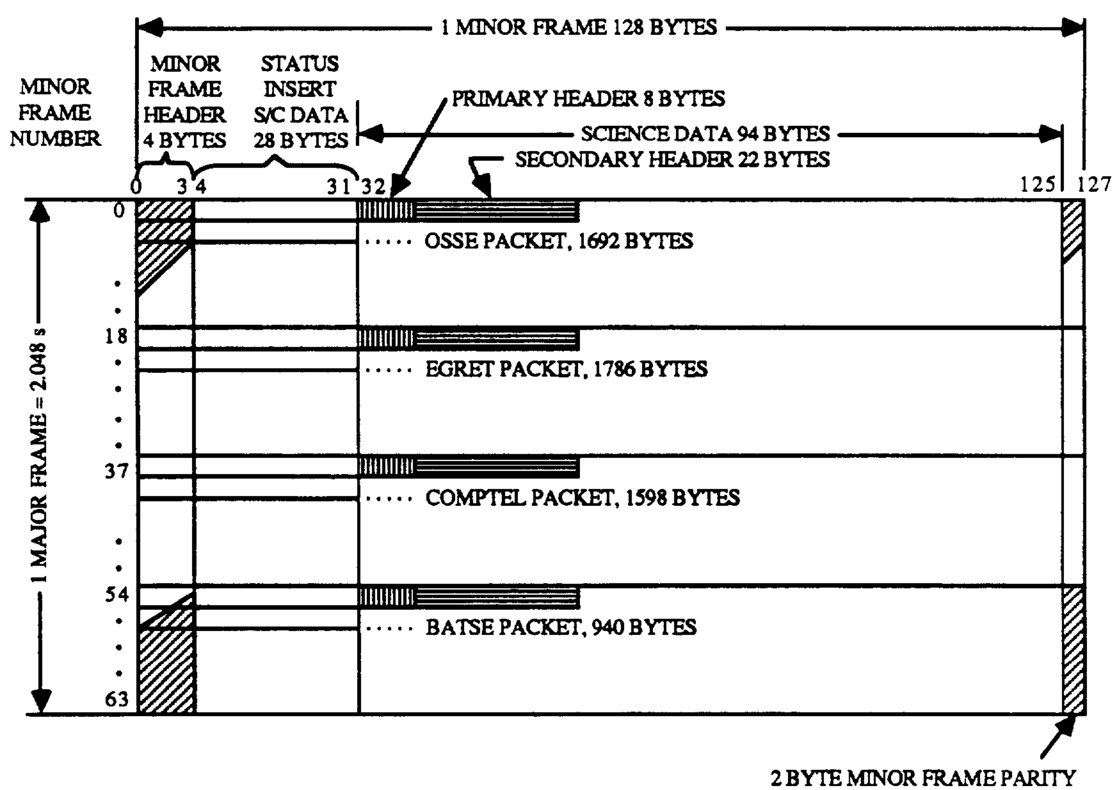


Figure 30. GRO Telemetry Format

As illustrated in Figure 31, the GRO SSC and the BATSE, OSSE, COMPTEL, and EGRET PI instrumenter sites are the five major nodes of the GRO Data Archive and Distribution System. They are networked together by the NASA Science Internet. A node is a location where there are data analysis hardware and software to support users. The GRO instrument collaboration teams consist of 15 research groups in 13 institutions. Currently, 9 of these groups have planned capabilities to support Guest Investigators:

OSSE:	Naval Research Laboratory, Northwestern University
COMPTEL:	Max Planck Institute for Extraterrestrial Physics (FRG), University of New Hampshire, Laboratory for Space Research (The Netherlands)
EGRET:	Goddard Space Flight Center, Max Planck Institute for Extraterrestrial Physics (FRG), Stanford University
BATSE:	Marshall Space Flight Center

These and other collaborator institutions can become subnodes to the system.

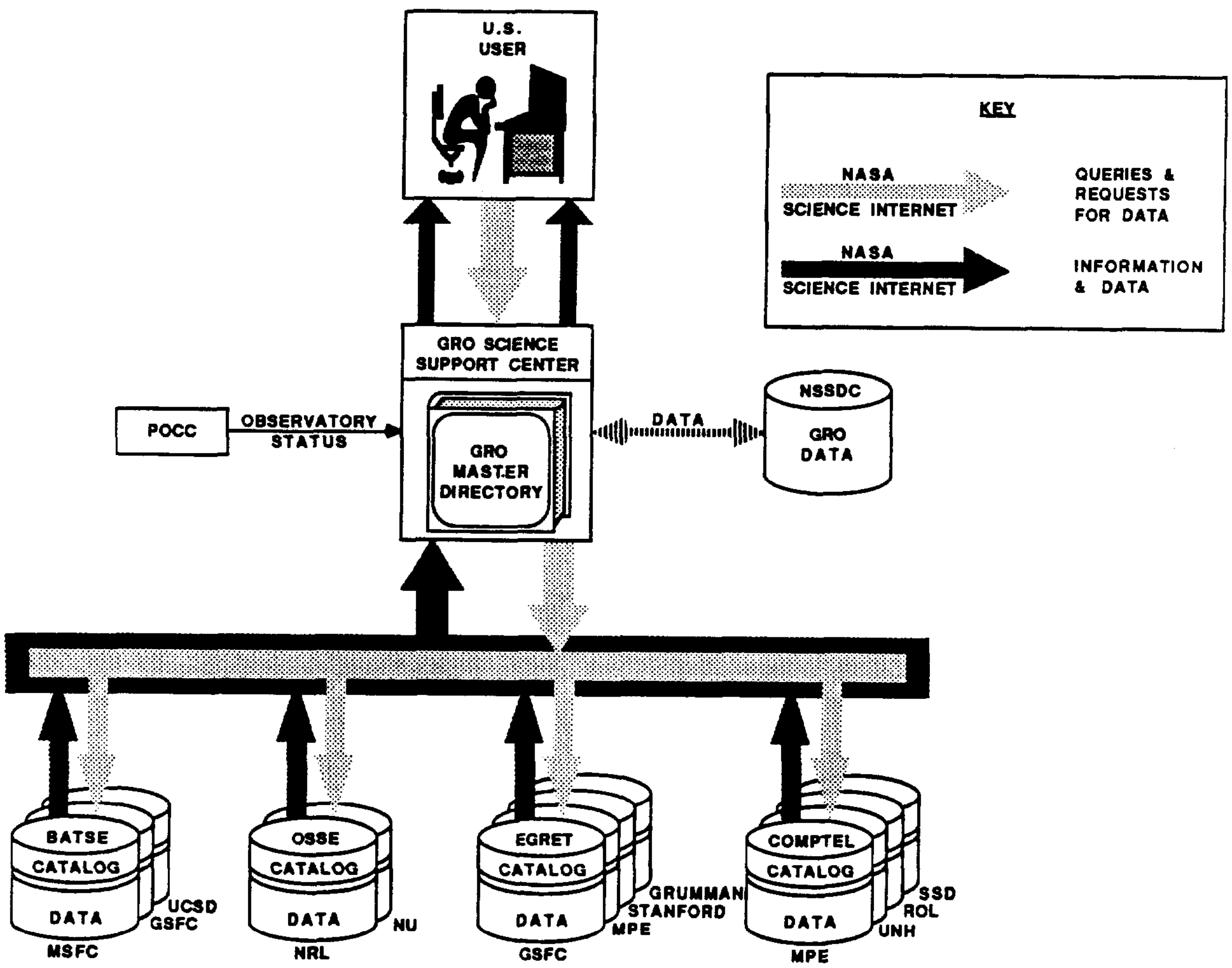


Figure 31. GRO Data Archive and Distribution System

The GRO Science Support Center (SSC) will be the source of information on the Guest Investigator Program, the characteristics of the science instruments, the status of GRO observations, and the use of GRO data, catalogs, and software in scientific research. The SSC, operated for NASA/GSFC by Computer Sciences Corporation, is staffed with astrophysicists, instrument specialists, scientific programmers, and other technical personnel to support the GI's use of the GRO. The main office of the SSC is located in the Laboratory for High Energy Astrophysics at GSFC; however, the SSC Instrument Specialists will be resident at the four PI instrumenter sites where they will assist with the interface between the instrument teams and the selected Guest Investigators.

Functions of the SSC also include: (a) the development and maintenance of an on-line electronic GRO Master Directory (Figure 31) of GRO data and software; (b) maintaining a library of GRO publications and documentation; (c) monitoring the release/submission of data/software products by the PI instrument teams for archiving at the National Space Science Data Center (NSSDC) and/or other selected archival repository; (d) ensuring that proper documentation and associated analysis software are submitted together with the data that are archived; (e) developing a standard hardware/software interface to give the user easy access to the diverse hardware/software capabilities at the different PI sites; (f) assisting GIs in the development of software for GRO analyses; and (g) supporting the GRO Project Scientist in organizing workshops and meetings.

Guest Investigator Program

The objective of the GRO Guest Investigator Program is to maximize the scientific return from the GRO Mission by broadening the scientific participation in the analysis of data, expanding the scope of observations, and conducting correlative and theoretical research that is closely tied to the GRO observations.

The structure of the GI Program takes into account the complex nature of the instruments and the associated data analysis. It requires that the Instrument Teams provide extensive support for the Program with respect to their individual instruments in addition to the support made available through the GRO SSC. A variety of modes of participation have been defined which allow GIs to structure their investigations to make the best use of the available resources, taking into account their own familiarity with the instruments and analysis techniques. The Program is generally structured in terms of four operational phases of the mission and five types of proposals that may be submitted by Guest Investigators. The mission phases have been previously outlined under "Observing Plan" in this report. Detailed descriptions of the specific modes of GI involvement are given for each GRO instrument in the NASA Research Announcement (NRA) for the GRO Phase 1 Guest Investigator Program (NRA 90-OSSA-4), dated January 30,1990.

Guest Investigators will also participate in committees and working groups which assist in planning mission operations. Representatives from the Guest Investigator community are included in the GRO User's Committee, the GRO Timeline Committee, the GRO Science Working Team, and the GRO Data Operations Group. Figure 32 illustrates the management structure supporting the Guest Investigator Program.

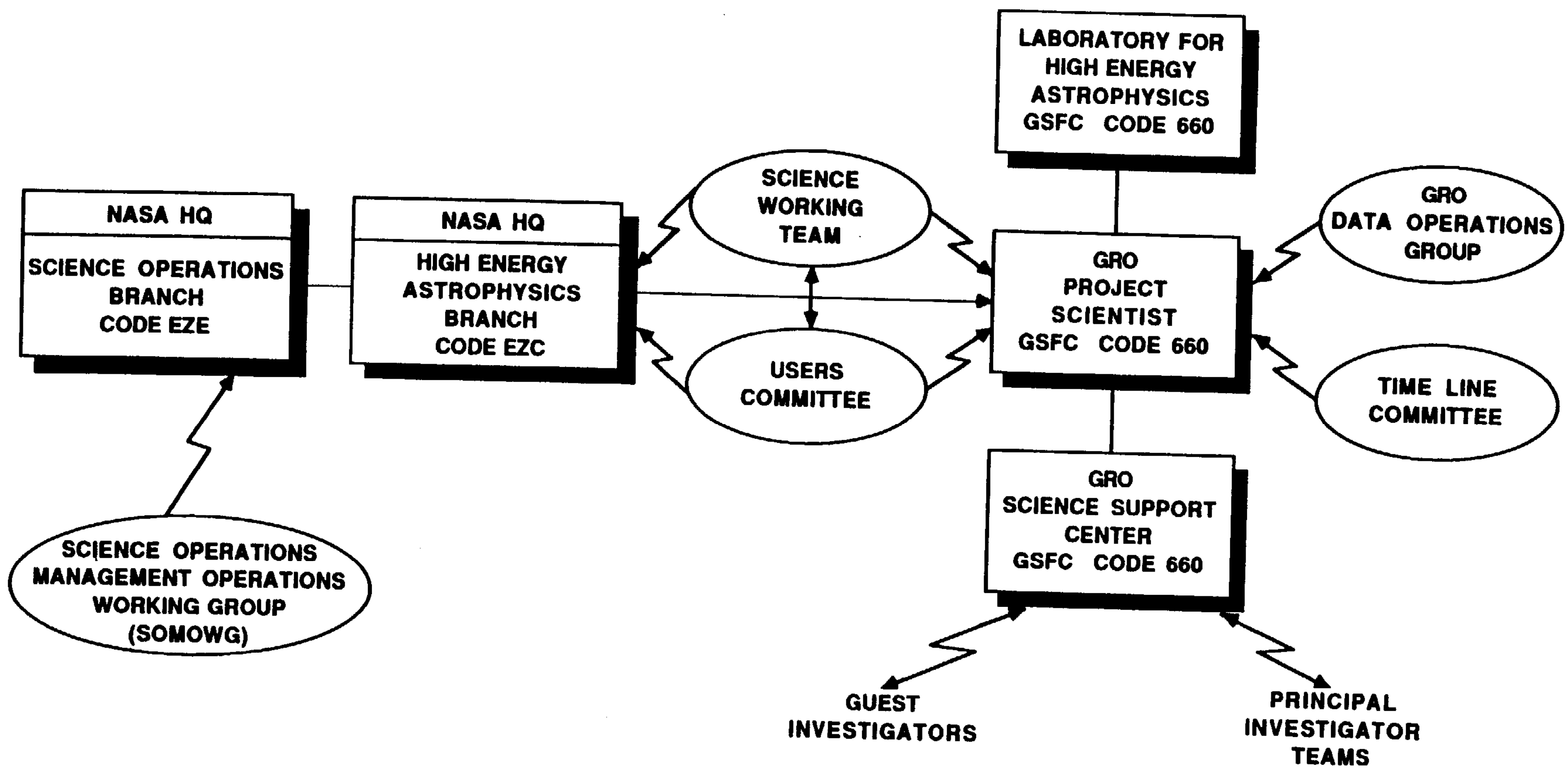


Figure 32. GRO Science Program Support Organization

MISSION MANAGEMENT

The Office of Space Science and Applications (OSSA), NASA Headquarters, is responsible for the overall direction and evaluation of the GRO Program. The Associate Administrator for OSSA has assigned Headquarters responsibility for the GRO Program to the Director of the Astrophysics Division who has designated a NASA Program Manager and a NASA Program Scientist. Within NASA, the Goddard Space Flight Center (GSFC) is responsible for project management of the Observatory and the communications, tracking, and data systems. Within GSFC, management is carried out by the GRO Project Office in the Flight Projects Directorate and is led by the designated GRO Project Manager and GRO Project Scientist. The Johnson Space Center (JSC) is responsible for the Space Shuttle. The Office of Space Operations, NASA Headquarters, has overall communications, tracking, and data acquisition oversight responsibility for the GRO mission. The Office of Space Flight, NASA Headquarters, has overall responsibility for the pre-launch activities at the Kennedy Space Center and the Space Shuttle flight operations conducted by the Johnson Space Center.

The responsible organizations and key personnel are:

<u>NASA Headquarters: Office of Space Science and Applications</u>

Dr. Lennard A. Fisk	Associate Administrator for Space Science and Applications
Alphonso V. Diaz	Deputy Associate Administrator for Space Science and Applications
Dr. Charles J. Pellerin, Jr.	Director, Astrophysics Division
Douglas R. Broome	Chief, Observatories Development Branch and GRO Program Manager
Nickolus O. Rasch	GRO Deputy Program Manager
Dr. Alan N. Bunner	Chief, High Energy Astrophysics Branch and GRO Program Scientist
Dr. Guenter R. Riegler	Acting Chief, Science Operations Branch and GRO Program Operations Manager

<u>NASA Headquarters: Office of Space Flight</u>

Dr. William B. Lenoir	Associate Administrator for Space Flight
Thomas Utsman	Deputy Associate Administrator for Space Flight
Robert L. Crippen	Director, Space Shuttle
Leonard S. Nicholson	Deputy Director, Space Shuttle Program
Brewster Shaw, Jr.	Deputy Director, Space Shuttle Operations

NASA Headquarters: Office of Space Operations

Charles T. Force	Associate Administrator for Space Operations
Jerry J. Fitts	Deputy Associate Administrator for Space Operations
Eugene Ferrick	Director, Space Network Division
Charles F. Fuechsel	Director, Communications & Data Systems Division
Robert M. Hornstein	Director, Ground Networks Division

Goddard Space Flight Center

Dr. John M. Klineberg	Director
Peter T. Burr, Jr.	Deputy Director
Dr. Dale W. Harris	Acting Director, Flight Projects
John A. Hrastar	GRO Project Manager
Thomas A. LaVigna	GRO Deputy Project Manager
Dr. Donald A. Kniffen	GRO Project Scientist
Martin A. Davis	GRO Observatory Manager
Jimmy E. Cooley	GRO Instrument Manager
Karl N. Schauer	GRO Operations Manager

Kennedy Space Center

Forrest S. McCartney	Director
Jay F. Honeycutt	Director, Shuttle Management and Operations
John T. Conway	Director, Payload Management & Operations
Joann H. Morgan	Director, Payload Projects Management

Johnson Space Center

Aaron Cohen	Director
Eugene F. Kranz	Director, Mission Operations
Charles W. Shaw	Flight Director (STS-37)
Nellie N. Carr	Payload Officer (STS-37)

Tandy Bruce	Payload Integration Manager (STS-37)

STS 37/Discovery Flight Crew

Col. Steven R. Nagel	Commander
Col. Kenneth D. Cameron	Pilot
Dr. Linda M. Godwin	Mission Specialist
Lt. Col. Jerry L. Ross	Mission Specialist
Dr. Jerome Apt	Mission Specialist

GRO Principal Investigators

Dr. Gerald J. Fishman	BATSE Principal Investigator Marshall Space Flight Center
Dr. James D. Kurfess	OSSE Principal Investigator Naval Research Laboratory
Dr. Volker Schonfelder	COMPTEL Principal Investigator Max Planck Institute for Extraterrestrial Physics
Dr. Carl E. Fichtel	EGRET Co-Principal Investigator Goddard Space Flight Center
Dr. Robert Hofstadter*	EGRET Co-Principal Investigator Stanford University
Dr. Klaus Pinkau	EGRET Co-Principal Investigator Max Planck Institute for Extraterrestrial Physics

* Deceased

GRO PROGRAM COSTS

Estimated costs of the GRO Program through Fiscal Year 1991 are:

Observatory and Instrument Development		\$557.1 Million
Mission Operations and Data Analysis		\$23.2 Million
	TOTAL	\$580.3 Million

PROJECT ACRONYMS

AC	Anti-Coincidence
ACAD	Attitude Control and Determination
ACE	Attitude Control Electronics
ACQ	Acquisition
ACS	Attitude Control Subsystem
ACT	Attitude Control Thruster
ADM	Attitude Determination Module
ADS	Astrophysics Data System
AESE	Airborne Electrical Support Equipment
AIE	Actuator Interface Electronics
AO	Announcement of Opportunity
AP	Applications Processor
ATT	Attitude
AXAF	Advanced X-Ray Astrophysics Facility
BATSE	Burst and Transient Source Experiment
BPA	Bus Protection Assembly
BPS	Bits per Second
BSA	Burst Spectrum Analyzer
CE	Central Electronics (OSSE)
C&DH	Command and Data Handling
C&DH	Communication and Data Handling
C&DHF	Command and Data Handling Facility
cm	Centimeter
CMD	Command
CMF	Command Management Facility
CMS	Command Management System

CO-I	Co-Investigator
CO-PI	Co-Principal Investigator
COMPTEL	Imaging Compton Telescope
CON or CONV	Converter
CPE	Control Processor Electronics
CPM	Charged Particle Monitor
CSC	Computer Sciences Corporation
CsI	Cesium Iodide
CSSA	Coarse Sun Sensor Assembly
CTV	Compatibility Test Van
CU	Central Unit
CU	Clemson University
DBMS	Data Base Management System
DCF	Data Capture Facility
DDCS	Data Distribution and Communication System
DE	Detector Electronics (OSSE)
DEA	Drive Electronics Assembly
DSN	Deep Space Network
DTM	Dual Thruster Module
D1	Upper Detector (COMPTEL)
D2	Lower Detector (COMPTEL)
E	East
E	Energy
EGRET	Energetic Gamma-Ray Experiment Telescope
EIA	Electrical Integration Assembly
ENG	Engineering
EPDS	Electrical Power Distribution System

ESA	European Space Agency
ESTEC	European Space Research and Technology Centre
ETR	Eastern Test Range
eV	Electron Volt
EVA	Extravehicular Activity
FDF	Flight Dynamics Facility (at GSFC)
FDM	Fill and Drain Module
FHST	Fixed-Head Star Tracker
FITS	Flexible Image Transport System
FOT	Flight Operations Team
FOV	Field of View
FRG	Federal Republic of Germany
FSS	Fine Sun Sensor
FSSA	Fine Sun Sensor Assembly
FWHM	Full Width at Half Maximum
G	Giga (10^9)
GDE	Gimbal Drive Electronics
GI	Guest Investigator
GGS	Goddard GRO Simulator
GN_2	Gaseous Nitrogen
GND	Ground
GRO	Gamma-Ray Observatory
GRODOG	Gamma-Ray Observatory Data Operations Group
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
GSTDN	Ground Spaceflight Tracking and Data Network
HGA	High Gain Antenna

HGAD	High Gain Antenna Drive
HQ	Headquarters
HQMI	NASA Headquarters Management Instruction
HST	Hubble Space Telescope
HTR	Heater
HV	High Voltage
HVPS	High Voltage Power Supply
ID	Identification
IGSE	Instrument Ground Support Equipment
IOE	Input/Output Electronics
IRU	Inertial Reference Unit
ISU	Instrument Switching Unit
JSC	Johnson Space Center
k	Kilo (10^3)
kg	Kilogram
KSC	Kennedy Space Center
LGA	Low Gain Antenna
LVPS	Low-Voltage Power Supply
m	Meter
m	Milli (10^{-3})
M	Mega (10^6)
MA	Multiple Access (TRDSS)
MCC	Mission Control Center
MDE	Motor Drive Electronics
min	Minute
MNVRS	Maneuvers
MO&DSD	Mission Operations and Data Systems Directorate

MOR	Mission Operations Room
MOU	Memorandum of Understanding
MPE or MPI	Max-Planck-Institut für Extraterrestrische Physik
MPS	Modular Power System
MSFC	Marshall Space Flight Center
MSOCC	Multisatellite Operations Control Center
MTA	Magnetic Torquer Assembly
n	Neutron
N	Newton
N_2	Nitrogen
NaI(Tl)	Sodium Iodide (Thallium)
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications Network
NCC	Network Control Center
NGT	NASA Ground Terminal
N_2H_4	Monopropellant Hydrazine
NiCd	Nickel-Cadmium
nm	Nautical Miles
NMI	NASA Management Instruction
NRA	NASA Research Announcement
NRL	Naval Research Laboratory
NSN	NASA Science Network
NSSC	NASA Standard Spacecraft Computer
NSSDC	National Space Science Data Center
NSTS	National Space Transportation System
NU	Northwestern University
OAT	Orbit Adjust Thruster

OATM	Orbit Adjust Thruster Module
OBC	On-Board Computer
OMV	Orbital Maneuvering Vehicle
OORM	On-Orbit Refueling Module
OPF	Orbiter Processing Facility
OSO	Office of Space Operations
OSSA	Office of Space Science and Applications (NASA)
OSSE	Oriented Scintillation Spectrometer Experiment
PACOR	Packet Processor
PB	Playback
PCU	Power Control Unit
PDF	Programmable Data Formatter
PDI	Payload Data Interleaver
PDM	Propellant Distribution Module
PDMP	Project Data Management Plan
PE	Processor Electronics
PE	Propulsion Electronics
PHA	Pulse Height Analyser
PI	Principal Investigator
PI/PDI	Payload Interrogator/Payload Data Interleaver
PMP	Premodulation Processor
PMT	Photomultiplier Tube
POCC	Project Operations Control Center
PREMOD	Premodulation
PREP	Preparation
PRI	Primary
PROD	Product(s)

PRU	Power Regulator Unit
PSE	Power Supply Electronics
psia	Pounds per square inch at 1 atmosphere
PWR	Power
QL	Quick Look
QSO	Quasi Stellar Object
REC	Recorder
RF	Radio Frequency
RIU	Remote Interface Unit
RMS	Remote Manipulator System
ROL	Laboratory for Space Research, Leiden
RT	Realtime
RTS	Realtime Sequence
RWEA	Reaction Wheel Electronics Assembly
RWA	Reaction Wheel Assembly
s	Second
SA	Single Access (TDRSS)
SA	Solar Array
SAA	South Atlantic Anomaly
SADA	Solar Array Drive Assembly
SCA	Signal Conditioning Assembly
SCHED	Schedule
sec	Second
SHU	Shunt
SIE	Sensor Interface Electronics
SIM	Simulation
SIRTF	Space Infrared Telescope Facility

SMM	Solar Maximum Mission
SN	Space Network
SOMOWG	Science Operations Management Operations Working Group
SPE	Sensor Processor Electronics
SPIF	Shuttle/POCC Interface Facility
sr	Steradian
SRPM	Sun-Referenced Pointing Mode
SSA	S-Band Single Access
SSC	Science Support Center
SSD	Space Science Division (ESTEC)
SSE	Sun Sensor Electronics
SSP	Standard Switch Panel
STACC	Standard Telemetry and Command Components
STDN	Spacecraft Tracking and Data Network
ster	Steradian
STINT	STACC Interface Unit
STS	Space Transportation System
SU	Stanford University
SURS	Standard Umbilical Release System
SWT	Science Working Team
TAC	Telemetry and Command
TAM	Three-Axis Magnetometer
TASC	Total Absorption Shower Counter (EGRET)
TBD	To Be Determined
TDE	Torquer Drive Electronics
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System

Tl	Thallium
TLM	Telemetry
TM	Telemetry
TOF	Time-of-flight
TR or T/R	Tape Recorder
TRK	Tracking
TTU	Time Transfer Unit
TYP	Typical
UAH	University of Alabama, Huntsville
UCSD	University of California, San Diego
UNH	University of New Hampshire
USCCS	User Spacecraft Clock Calibration System
UTC	Universal Time, Coordinated
V	Velocity
VALID	Validation
VPF	Vertical Processing Facility
VSS	Viewing Support System
W	Watt
W	West
WSGT	White Sands Ground Terminal
ZLV	Z-axis Local Vertical (Space Shuttle)
ZSI	Z-axis Solar Inertial (Space Shuttle)